

# **The contribution of tidal fluvial habitats in the Columbia River Estuary to the recovery of diverse salmon ESUs**

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## INTRODUCTION AND STUDY OBJECTIVES

The 2008 Biological Opinion on Operation of the Federal Columbia River Power System established estuary restoration goals for ten-year survival improvements of 9% for ocean-type and 6% for stream-type ESUs. To support these goals, a qualitative assessment process (*Columbia River Estuary Recovery Plan Module*) was devised to identify limiting factors and to prioritize estuary restoration actions based on their presumed survival benefits. The method ranks the potential benefits of various restoration projects based on published results and professional judgments about their relative effectiveness. Empirical estimates of survival benefits are unavailable, however, and the actual contributions of single or cumulative estuary actions to the survival goals in the Biological Opinion are unknown.

Today scores of wetland restoration projects have been undertaken in the estuary as a method to recover at-risk salmon populations throughout the Columbia River basin, based in part on the latest information about the estuary's role as a productive nursery ground for juvenile salmon (Bottom et al. 2005; 2008; 2011; Roegner et al. 2008; 2010; 2012; Johnson et al. 2011). Recent genetic data collected in the estuary have shown evidence of important stock-specific differences in estuarine habitat use (Bottom et al. 2008; Teel et al. 2009) that have not been considered in the selection or design of restoration projects. Moreover, the population response to estuary restoration remains poorly understood because Research, Monitoring, and Evaluation (RME) programs have focused exclusively on the performance of estuarine-rearing juveniles rather than their ultimate contribution to adult returns. We proposed an integrated study program to target these uncertainties and specifically to address:

1. What types and spatial distribution of estuarine habitats must be restored to satisfy the migratory and rearing requirements of diverse Columbia River stocks?
2. Do improvements in estuarine rearing habitat promote salmon recovery?

The overarching goal of this research is to determine the estuary's contribution to the spatial structure and life history diversity of Columbia River salmon stocks and the implications for strategic estuary restoration. To achieve this long-term goal, we proposed four research objectives corresponding to each of the following questions:

1. How are genetic stock groups distributed throughout the estuary?
2. Do salmon life history, habitat use, and performance vary by stock?
3. Which juvenile life histories contribute to adult returns, and does estuarine habitat restoration benefit population resilience?
4. How much restoration is needed to insure stock persistence?

This annual report summarizes by objective our research progress in 2011, the second year of a multiyear endeavor.

## METHODS AND RESULTS

**Objective 1: Characterize the temporal and spatial distribution of Chinook salmon genetic stock groups throughout the estuary, with emphasis on tidal reaches from Rkm 75 to Bonneville Dam.**

*Task 1.1. Determine bimonthly genetic stock-group composition at three beach-seining sites in each of the six tidal fluvial reaches (C – H) of the estuary.*

From March 2010 to April 2012 we conducted a series of synoptic genetic surveys to define the patterns of salmon stock distribution and life history from the river mouth to Bonneville Dam, with emphasis on undersampled estuary reaches C – H (Simenstad et al. 2005) and habitat types above Rkm 75 (Figure 1). We also sampled a single lower-estuary site along the Oregon shore in the lower portion of reach A (Point Adams Beach) (see Task 1.2) as an indicator of genetic variation and life histories among salmon outmigrants. To characterize reach-scale diversity in stock composition, we sampled three different habitat types within reaches C - H: main stem, back water, and tributary confluence.

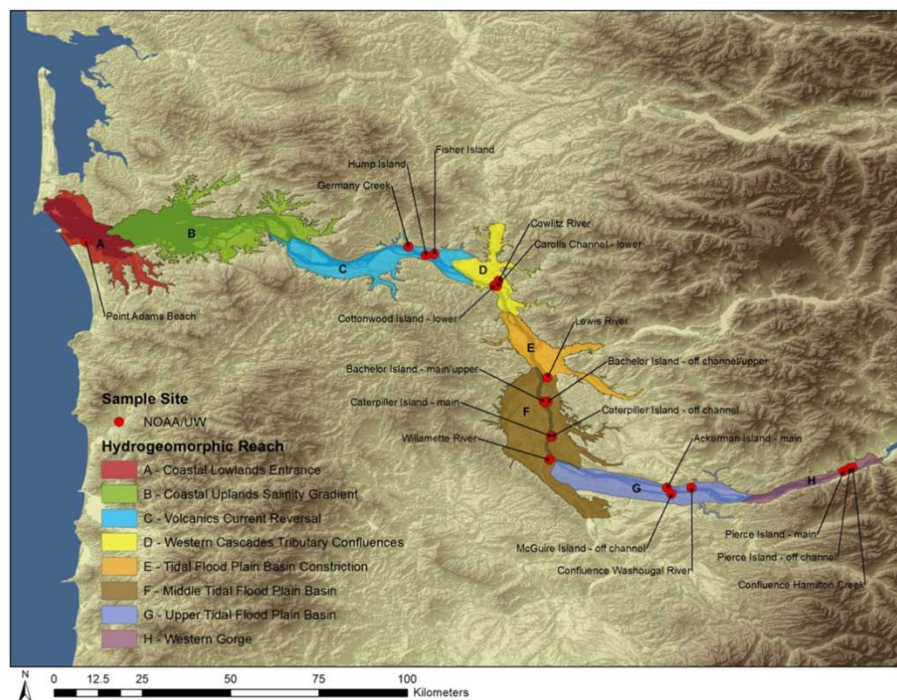


Figure 1. Map of genetics sampling sites in 2010-11 by estuary reach (A – H). Reach designations coincide with each of eight hydrogeomorphic reaches designated by Simenstad et al. (2005).

Standard fish sampling methods during the genetics and outmigrant collections followed Roegner et al. (2009) and Bottom et al. (2011). Briefly, fish were sampled by beach or bag seine. Length and weight were measured for up to 70 salmon of each species. Fin tissue samples were collected from a maximum of 30 Chinook salmon for genetic analysis, and analyzed as described below. All measured salmonids were examined for marks and tags to ascertain hatchery origin,

and those with coded-wire tags were retained. Subyearling and yearling life history designation of salmon was determined by length and capture day (day of year). Fry are subyearlings  $\leq 60$  mm fork length (FL) and fingerlings are subyearlings that exceed 60 mm. Generally, larger fish captured in winter and spring were considered yearlings ( $>70$  mm in January,  $>90$  mm in March, and  $>120$  mm in May). Smaller fish and those captured in July through November were considered subyearlings.

Fish tissue storage and data collection methods for the genetic analyses are described in Teel et al. (2009). We used microsatellite DNA loci that have been standardized among several West Coast genetics laboratories (Seeb et al. 2007), as well as on previous genetic studies of Chinook salmon in the Columbia River Basin (e.g., Myers et al. 2006; Waples et al. 2004), to estimate the stock origins of Chinook salmon collected in the estuary. Allocations to individual baseline populations were summed to estimate contributions of 11 regional stock groups (Appendix Table 1), and proportional stock compositions of estuary samples were estimated using the likelihood model of Rannala and Mountain (1997) as implemented by the genetic stock identification computer program ONCOR (Kalinowski et al. 2007). Precisions of the stock composition results were estimated by bootstrapping baseline and mixture data 100 times (Kalinowski et al. 2007).

Information and data sources for the 45 Columbia River Basin and coastal populations in our baseline are given in Appendix Table 1. In the interior Columbia River, genetic groups identified using the microsatellite baseline include Snake River spring/summer (Snake Sp), Snake River fall (Snake F), and mid- and upper Columbia River spring run populations from east of the Cascade Mountains (M/UCR Sp). Also in the interior Columbia River are the upper Columbia River summer/fall (UCR Su/F) stock group and the fall populations in the Deschutes River (Deschutes F). The UCR Su/F stock group includes summer run Chinook salmon populations in the upper Columbia River and “upriver bright” fall populations, including those in the Hanford Reach area. Upriver bright fall fish also spawn in several Columbia Gorge tributaries and in main-stem areas just below Bonneville Dam, likely the result of hatchery programs (Myers et al. 2006). The Spring Creek Group (SCG F) is a “tule” fall stock originating in the Spring Creek NFH in the Columbia River Gorge area and has been widely propagated throughout the lower Columbia River (Myers et al. 2006). Also in the lower Columbia River are the Willamette River spring (WR Sp) and the West Cascade spring (WC Sp) and fall (WC F) stock groups comprised of fish originating in several tributaries and hatcheries (Myers et al. 2006). Chinook salmon in the Columbia River also include individuals from the Rogue River stock which was introduced from southern Oregon into the Columbia River beginning in the 1980’s as part of a continuing effort to enhance fisheries in off-channel areas (North et al. 2006). We therefore included Rogue River (Rogue) data in our baseline dataset to identify fish descended from those stock transfers. We also included north Oregon and south Washington coastal baseline data (Coastal) to estimate migrants from outside the Columbia River Basin into lower estuary beach seine habitats (Roegner et al. 2012).

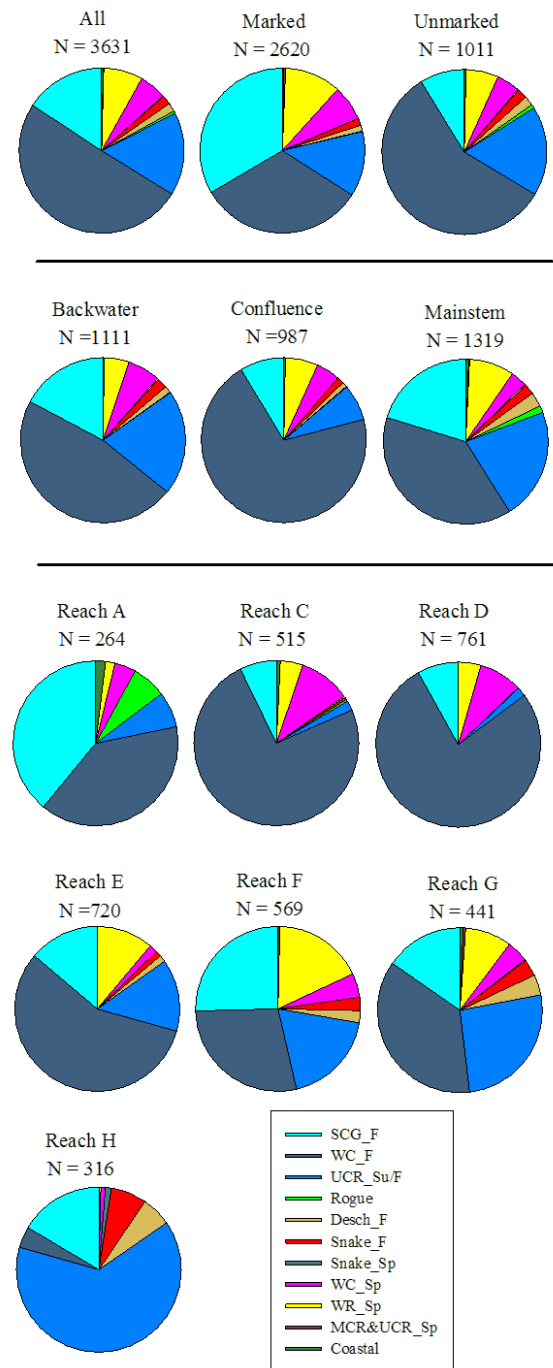
For analysis, samples were grouped by reach and by month to estimate proportional stock compositions. Because relatively few samples were obtained in September and November, samples from those months were combined. Samples collected in reaches D (n=54) and E (n=24) in February 2012 were included with January samples and samples collected in April 2012 in reaches G (n=12) and H (n=17) were included with March samples. We also grouped samples by

life history type based on size at capture, as described above. Genetic stock compositions were also used to evaluate diversity in each reach and habitat type by applying standard indices of community diversity: 1) number of stocks ( $S_G$ ), 2) the Shannon–Wiener diversity index ( $H'_G = \sum [P_i \times \ln P_i]$ , where  $P_i$  is the proportional composition of stocks in the sample), and 3) stock evenness ( $J'_G = H'/H_{\max G}$ , where  $H_{\max G} = \ln(S_G)$ ).

## Results

Genetic data from a total of 3631 samples were used to estimate proportional stock compositions of Chinook salmon juveniles captured in the Columbia River estuary (Appendix Table 2). Overall, approximately 51% of the samples analyzed were estimated to be from the West Cascade tributary fall run (WC F) genetic stock group (Figure 3). The Upper Columbia River summer/fall (UCR Su/F), Spring Creek Group fall (SCG F), Willamette River spring (WR Sp), and West Cascade spring (WC Sp) stock groups were estimated to contribute from 5 - 17%. Small (1 - 2%) percentages were also estimated for the Deschutes River fall (Deschutes F), Snake River fall (Snake Fall), and Rogue River fall (Rogue) stocks. Mid and Upper Columbia River spring (M/UCR Sp), Snake River spring (Snake Sp), and Oregon and Washington coastal fall/spring (Coastal) stock groups comprised less than 1% of the total sample. The genetic stock assignments of individual fish in our analysis provided additional evidence that the minor contributing populations were present in our samples. Some individuals from each of the 11 genetic stock groups, including interior basin spring run stocks, had high relative assignment probabilities ( $>0.90$ ).

Figure 3. Estimated proportions of 11 genetic stock groups in samples of Chinook salmon collected at Columbia River estuary sites from 2010 to 2012. Samples are grouped by month and by life-history type (described in text). Results are shown for sample sizes greater than 25 fish (see Appendix Table 2). Estimates for fry in January are for reaches C and D combined and E and F combined.



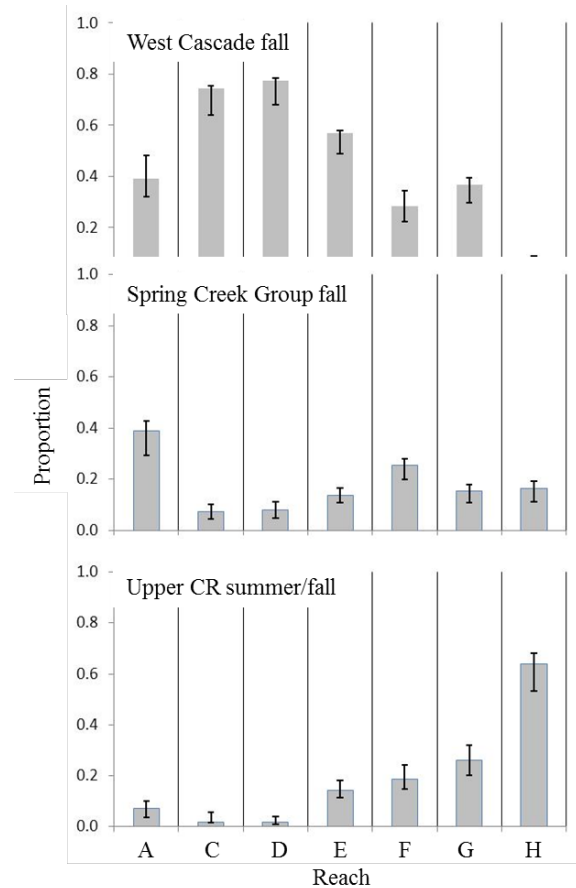


Figure 4. Estimated proportions of three major contributing genetic stock groups to samples of Chinook salmon collected at Columbia River estuary sites from 2010 to 2012. Sample sizes are provided in Appendix Table 2.

Stock compositions differed among reaches (Figure 3 & 4, Appendix Table 2). The largest percentages of WC F stock were observed in reaches D (77%, CI = 68 - 79%) and C (74%, CI = 64 - 75%). Reaches A, E, F, and G also had substantial contributions of the WC F stock (28 - 59%). SCG F comprised greater than 7% of the samples in all reaches and was most evident in reaches A (39%, CI = 29 - 43%) and F (25%, CI = 20 - 28%). Reach H had the largest proportions of UCR Su/F (64%, CI = 53 - 68%) and Snake F (7%, CI = 4 - 14%) stocks and the smallest contribution of WC F (4%, CI = 2 - 9%). UCR Su/F stock also contributed substantially to reaches E, F, and G (14 - 26%). WR Sp stock was primarily estimated in reaches E, F, and G (9 - 18%).

In addition to the spatial structure in stock compositions outlined above, stock proportions differed greatly by season and life-history type as revealed by analyses of samples grouped within each reach by month and by fish size (Figure 5; Appendix Table 2). Although relatively few in number, most yearlings during March in reaches E and F were WR Sp stock (84 - 89%). In reaches C and D, WR Sp also contributed substantially (47 and 55%) as did WC Sp (46 and 36%). Yearlings sampled in January in reach E also included WR Sp (35%) but the largest estimated percentage was WC F (53%).

Relatively few fry-sized juveniles were captured in January, but those samples included substantial proportions of both fall and spring run Chinook salmon (Figure 5; Appendix Table 2). WC Sp were an estimated 39% of the combined reaches C and D sample and WR Sp contributed 39% to the reaches E and F sample. In March, May, and July, fry in reaches C, D, and E were predominantly WC F stock (58 - 95%). In contrast, fry sampled in reaches F, G, and H showed strong shifts in stock compositions from March to May. During March, the SCG F stock was predominant (39 - 50%). In May, SCG F fry were still found in reach F (20%) but we also observed increased proportions of WC F (50%) and UCR Su/F (19%) fry. Similarly, increased proportions of UCR Su/F fry were estimated for Reach G (34%) and Reach H (75%) during May. We captured very few fry-sized subyearlings in reaches F, G, and H during July.



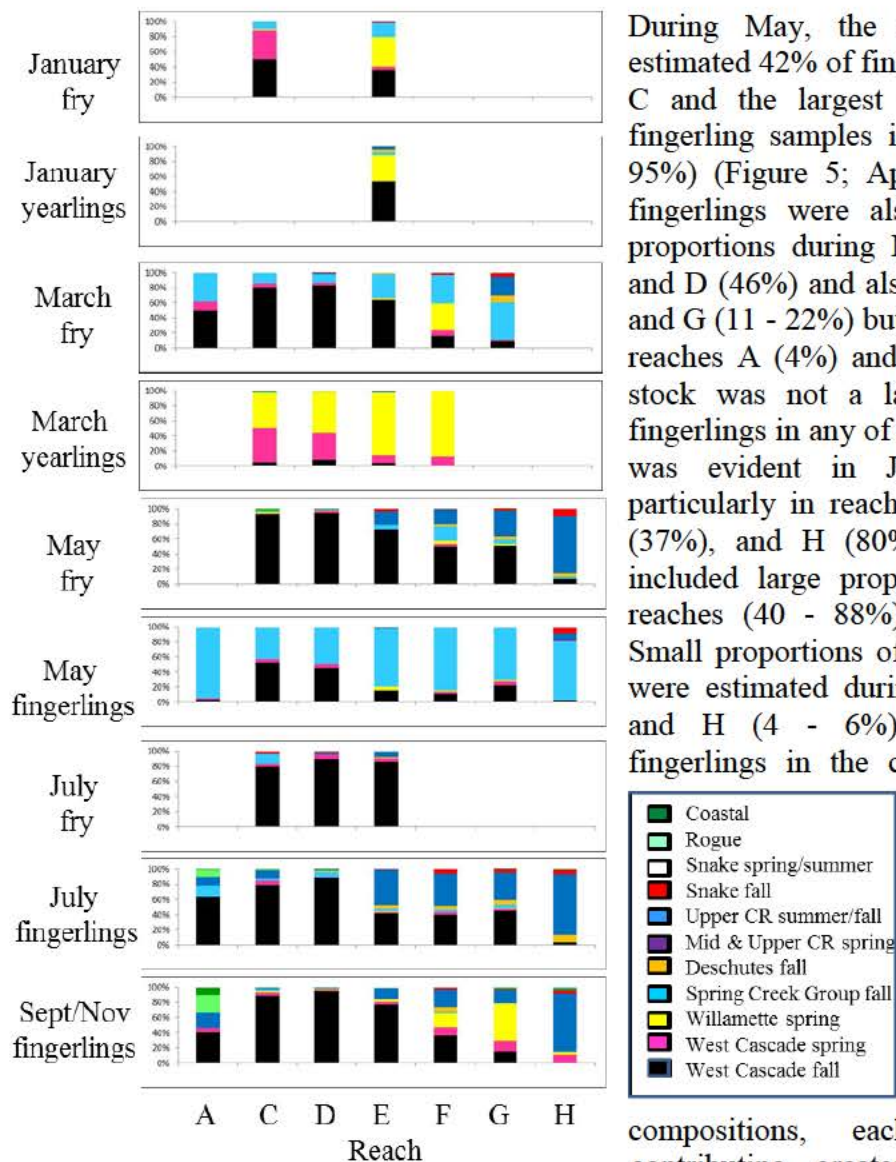


Figure 5. Proportions of individuals assigned to each of 11 genetic stock groups in samples of Chinook salmon collected at Columbia River estuary sites during 2010 and 2011. Samples grouped by life-history type and reach.

During May, the SCG F stock was an estimated 42% of fingerlings sampled in Reach C and the largest estimated contributor to fingerling samples in all other reaches (50 - 95%) (Figure 5; Appendix Table 2). WC F fingerlings were also present at substantial proportions during May in reaches C (52%) and D (46%) and also present in reaches E, F, and G (11 - 22%) but only small proportions in reaches A (4%) and H (3%). The UCR Su/F stock was not a large contributor to May fingerlings in any of the reaches (0% - 8%) but was evident in July fingerling samples, particularly in reaches E (46%), F (43%), G (37%), and H (80%). July fingerlings also included large proportions of WC F in all reaches (40 - 88%) except Reach H (4%). Small proportions of Snake F fish fingerlings were estimated during July in reaches F, G, and H (4 - 6%). Stock proportions of fingerlings in the combined September and November samples were highly variable across reaches with WC F predominant in reaches C, D, and E (77 - 94%) and UCR Su/F in Reach H (72%). Other reaches showed more diversity in compositions, each with four stocks contributing greater than 10%. Estimates included Rogue (24%) and Coastal (10%) in Reach A and WR Sp and WC Sp spring run fingerlings in reaches E, F and G (11% - 49%).

The percentage of marked fish in our samples was greatest in Reach A (53%) and smallest in Reach E (18%) (Appendix Table 2). Samples from other reaches had intermediate proportions of marked fish (22 - 38%). Marked fish rates also varied among life-history types. Our fry samples were nearly entirely comprised of unmarked fish in all reaches in January and March and included increased proportions of marked fish in May (0% - 5%) and July (2 - 8%). Fingerlings had greater marked fish rates in May (33 - 96%), July (28 - 67%) and in September/November (16 - 50%). Yearlings were also mostly marked fish (67 - 93%) except in Reach E in January (18%) and March (39%).



Measures of stock diversity and stock evenness indicated lower levels in reaches C ( $H'=0.96$ ,  $J'=0.44$ ) and D ( $H'=0.82$ ,  $J'=0.46$ ) than in other reaches (Figure 6). Reaches F ( $H'=1.67$ ,  $J'=0.80$ ), G ( $H'=1.67$ ,  $J'=0.73$ ) and A ( $H'=1.38$ ,  $J'=0.$ ) showed the highest values for those metrics. The number of stocks per reach was highest in Reach G ( $S=10$ ) and lowest in Reach D ( $S=6$ ). Comparisons among habitat types showed that confluence sites had lower stock diversity levels ( $S=9$ ,  $H'=1.09$ ,  $J'=0.50$ ) than mainstem ( $S=11$ ,  $H'=1.64$ ,  $J'=0.68$ ) or back channel ( $S=11$ ,  $H'=1.48$ ,  $J'=0.62$ ) habitats (Figure 7). Unmarked fish were lower in stock diversity ( $H'=1.33$  vs  $H'=1.52$ ), total stocks (10 vs 11) and stock evenness ( $J'=0.58$  vs  $J'=0.66$ ) compared with marked fish (data not shown).

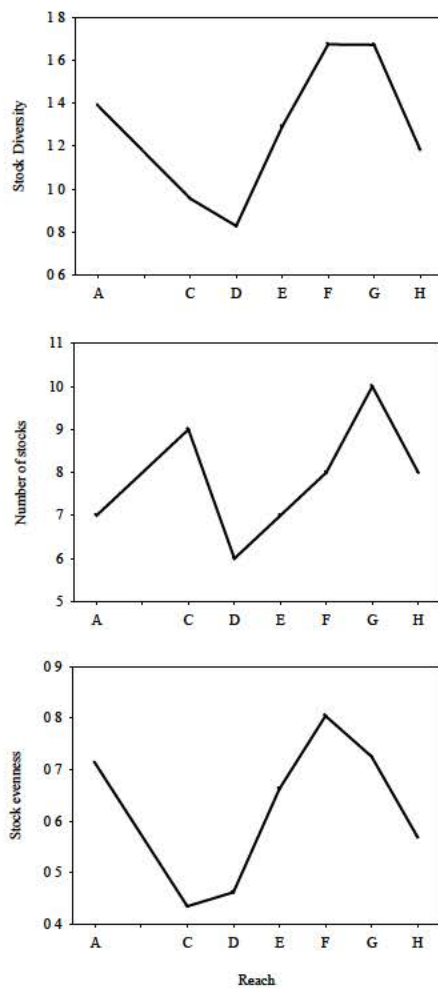


Figure 6. Genetic stock diversity ( $H_G'$ ), number of stocks ( $S_G$ ), and stock evenness ( $J_G'$ ) of Chinook salmon collected at Columbia River estuary sites during 2010 and 2011. Samples are grouped by reach.

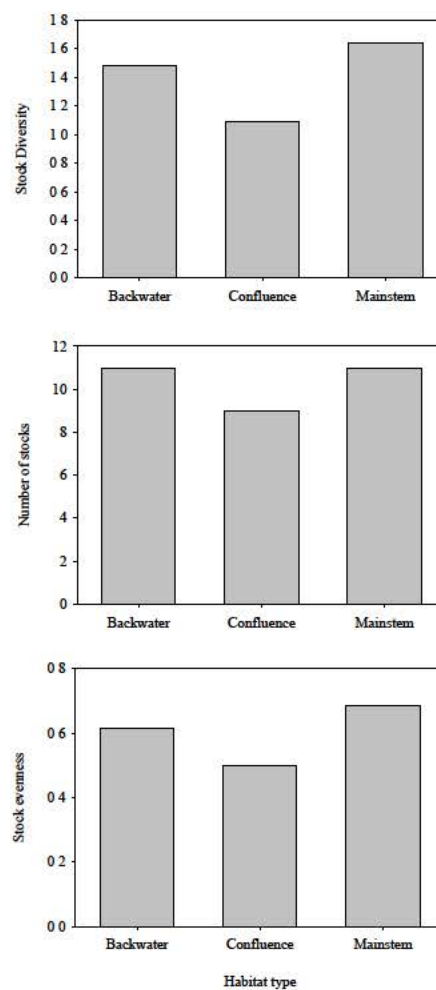


Figure 7. Genetic stock diversity ( $H_G'$ ), number of stocks ( $S_G$ ), and stock evenness ( $J_G'$ ) of Chinook salmon collected at Columbia River estuary sites during 2010 and 2011. Samples are grouped by habitat type.

*Task 1.2. Measure Chinook genetic and life history composition of juvenile out-migrants near the estuary mouth.*

Point Adams Beach (PAB; rkm 20) serves as a long-term reference site for juvenile salmon monitoring (sampled since 2002 excluding 2009) and also provides a comparison to fish assemblages sampled by purse seine at nearby main channel sites (Weitkamp et al. 2012). During 2010 and 2011, beach seine sampling at PAB (Figure 1) was conducted biweekly from January through July and monthly thereafter, usually within 2 h of low tide. Standard sampling techniques were employed (Roegner et al. 2012). In addition to the salmon sampling procedures referenced above, we also measured and released a representative sample of up to 30 individuals of each non-salmonid species, and counted and released the remaining fish. The total catch from the ~400 m<sup>2</sup> seine area was standardized as density (ind/m<sup>2</sup>). Time series of density and mean size were generated to ascertain population status of salmon and the dominant fish species. Results are compared to reference data collected at PAB from 2002-2008 and from purse seine catches (Weitkamp pers. comm.).

### Results

During 2010 and 2011 we made 100 beach seines and sampled over 18000 fish. A brief discussion of the fish community at PAB is found in Appendix Table 3; salmon are discussed below.

The Chinook salmon population was primarily comprised of fry- (15 - 20%) or fingerling-sized (76-83%) subyearlings, but also included a low number of yearlings found during March and April (Table 1; Figure 8A). Subyearlings were present year-round, and were most abundant June – July (Figure 9), which conforms to the typical peak of subyearling migration at PAB and the lower estuary (Roegner et al. 2012). However, densities during May and June 2011 greatly exceeded previous observations at this site (with a maximum of 1.5 ind/m<sup>2</sup>). Mean size by time was similar among years and exhibited a positive increase with time, as is typically observed. The proportion of hatchery marks did not differ between years (~63%, Table 1).

Chum salmon were primarily fry-sized subyearlings (Figure 8B) They occurred at relatively low abundance (< 0.05 ind/m<sup>2</sup>) compared to previous years except one sample in April 2010; mean sizes in 2010 tended to be smaller than in 2011 or previous years (Figure 9).

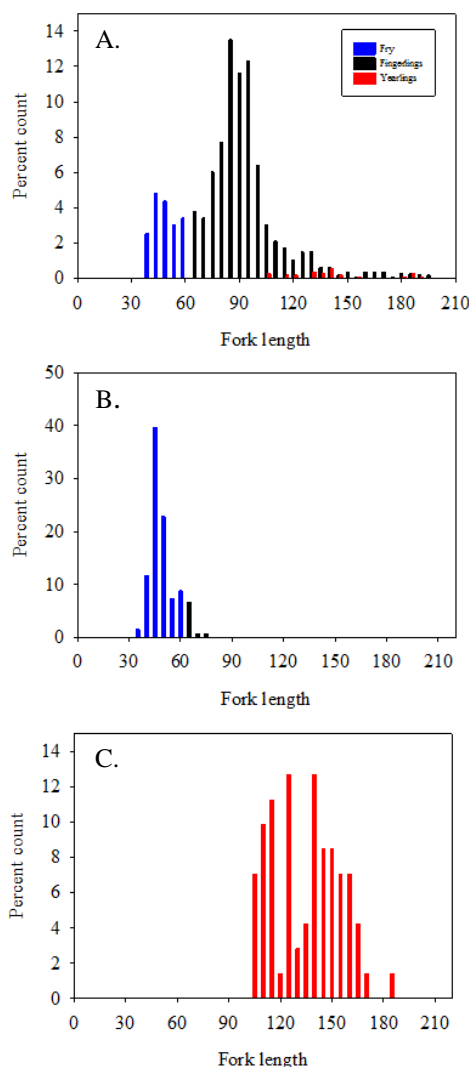


Figure 8. Size-frequency and life history stages of A. Chinook, B. chum, and C. coho salmon.

Coho salmon are not commonly sampled at PAB or other shallow water mainstem sites (Bottom et al. 2011; Roegner et al. 2012), and when found are at low density ( $< 0.05$  ind/m<sup>2</sup>). However, coho were relatively abundant in both 2010 and 2011, and the data for PAB suggests the main migration period in shallow water is limited to a narrow window in late April to mid-May, and our previous surveys inadequately sampled this period. These are primarily hatchery-reared yearling fish (Figure 8C; Table 1) and their abundance is likely related to hatchery release patterns. Sizes by date conformed to previous observations (Figure 9).

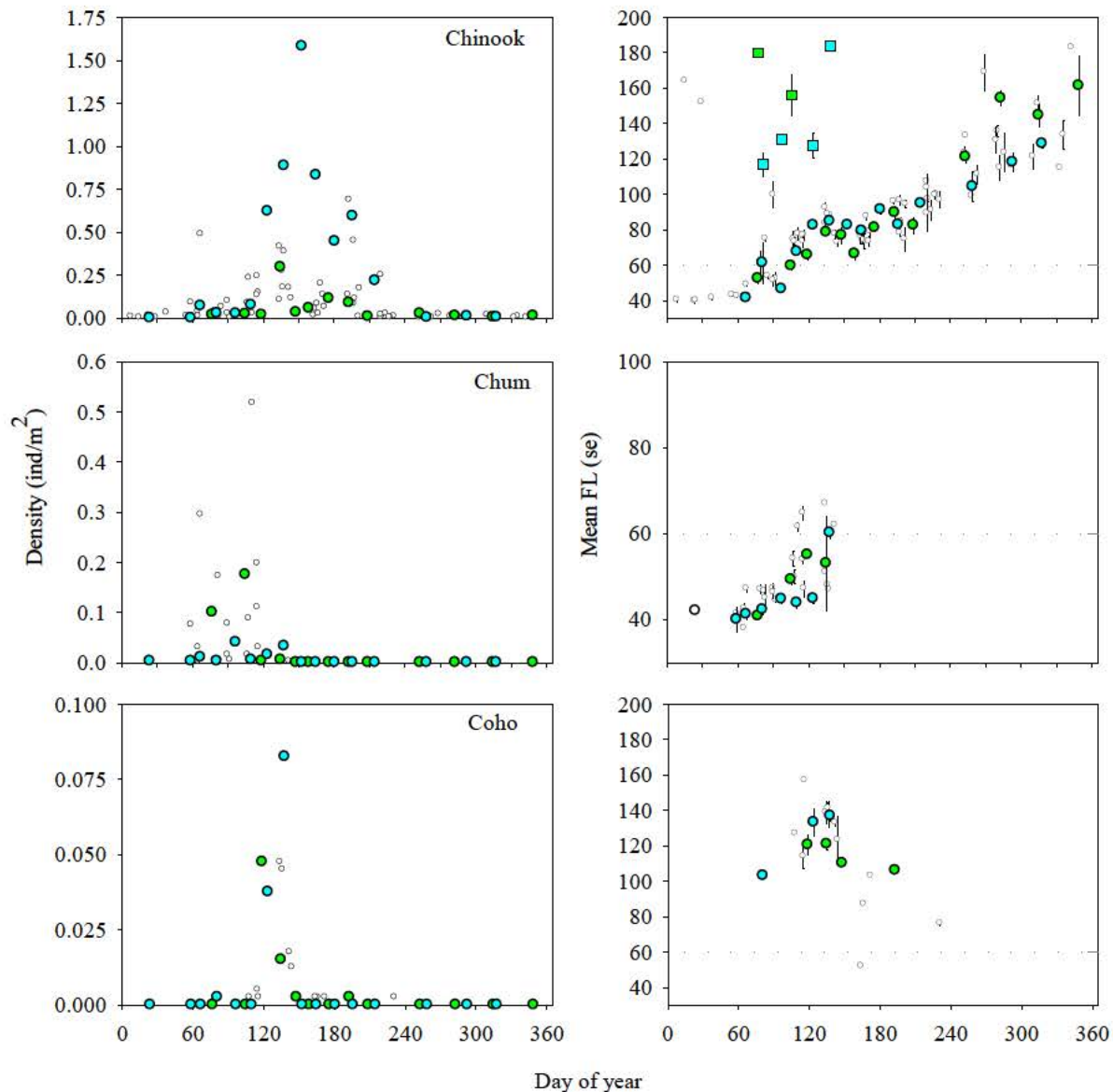


Figure 9. Time series of density (left) and mean fork length (right) for Chinook, chum, and coho salmon sampled at PAB during 2010 (green) and 2011 (blue) relative to 2002-2008 (white).

Table 1. Life history, origin, and genetic samples of salmon species based on measured individuals during 2010 and 2011.

	Year	Life history	N	%Total	Mark	%Mark	CWT	Genetics
Chinook	2010	Fry	53	15.3	3	5.7	0	36
		Fingerling	289	83.5	177	61.2	4	175
		Yearling	4	1.2	3	75.0	0	2
		TOTAL	346		183	52.9	4	213
	2011	Fry	160	20.1	5	3.1	0	101
		Fingerling	615	77.2	391	63.6	21	219
		Yearling	22	2.8	22	100	9	20
		TOTAL	797		408	52.4	30	340
Chum	2010	Fry	69	98.6	0	0	0	0
		Fingerling	1	1.4	0	0	0	1
		Yearling	0	0.0	0	0	0	0
		TOTAL	70		0	0.0	0	1
	2011	Fry	61	92.4	0	0	0	35
		Fingerling	5	7.6	0	0	0	5
		Yearling	0	0.0	0	0	0	0
		TOTAL	66		0	0.0	0	40
Coho	2010	Fry	1	3.6	1	100	0	1
		Fingerling	0	0	0	0	0	0
		Yearling	26	96.4	23	85.2	0	0
		TOTAL	27		23	85.2	0	1
	2011	Fry	1	2.1	1	100	0	1
		Fingerling	0	0	0	0	0	0
		Yearling	46	97.9	32	69.6	4	5
		TOTAL	47		33	70.2	4	6

We compared abundances and mean sizes of subyearling Chinook and chum salmon sampled contemporaneously from beach and purse seines. CPUE was standardized to a 1000 m<sup>2</sup> area (purse seine data supplied by L. Weitkamp). Both species of subyearling salmon were far more abundant in shallow water than in main channel habitats (Figure 10); in contrast yearling fish of all species were less abundant at beach seine sites but well represented in purse seine catches (Weitkamp et al. 2012). Subyearling fish also tended to be larger in the main channel.



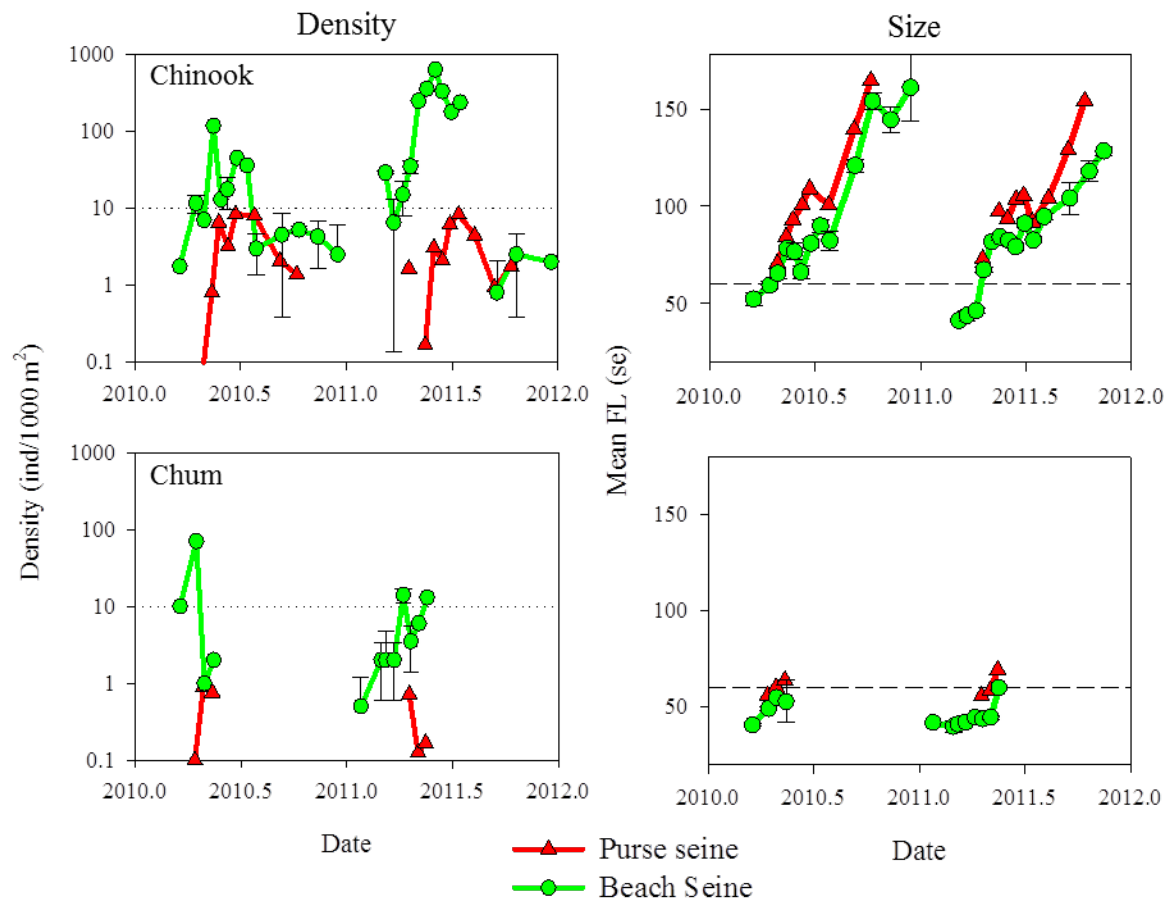


Figure 10. A comparison of purse- and beach seine density (left) and mean fork length (right) of Chinook (top) and chum (bottom) salmon during 2010 and 2011.

Genetics data are presented above in Task 1.1 and Figures 3-5.

*Task 1.3. Determine migration and residency patterns of tagged Chinook stocks at PIT detection sites in shallow off-channel habitats of selected lower, mid-, and upper estuary reaches.*

Passive Integrated Transponder (PIT) detection stations established in wetland sites has allowed determination of habitat residence times for a variety of tagged stocks. In 2011 we continued operation of one instream PIT detection array at Russian Island and established new instream PIT detection arrays at Woody Island (rkm 47) and Wallace Island (rkm 80) (Figure 11). Results from each site are discussed below.



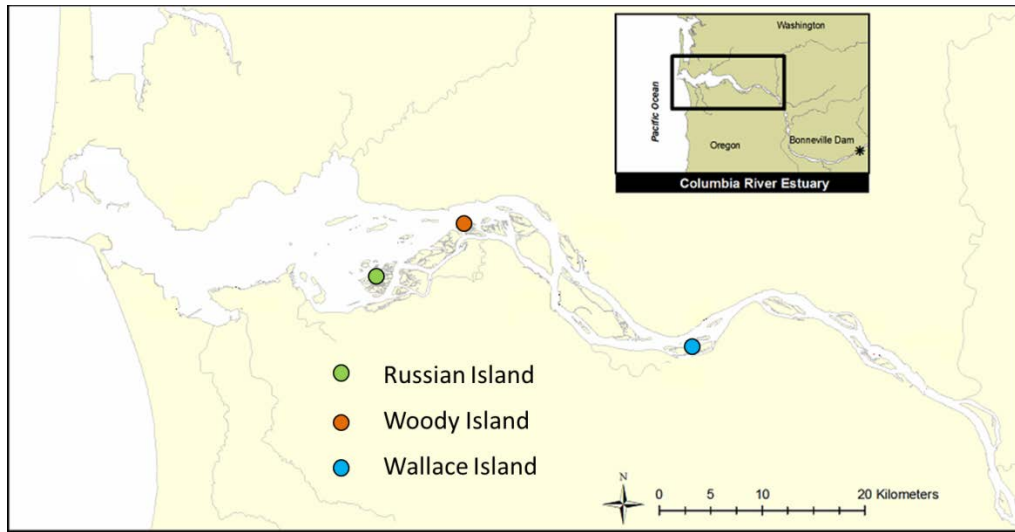


Figure 11. Wetland locations for three PIT tag monitoring stations in 2011.

#### Russian Island

The Russian Island PIT detection array has been seasonally operational since spring 2008; sampling in 2011 occurred from 22 March to 28 September. A total of 21 PIT tagged fish were detected: 17 Chinook salmon, 2 steelhead, 1 coho salmon, and 1 unknown fish. The total number of detections in 2011 was intermediate compared to previous years: in 2008, 2009, and 2010, we recorded 14, 33, and 28 unique detections, respectively. Fourteen of the Chinook salmon detected in 2011 were fall run and the remaining three were spring run. The fall-run Chinook salmon were in residence for an average of 3.3 d and a maximum of 38.5 d. Seventy one percent of the fall Chinook salmon were released above Bonneville Dam and 7% were released above Lower Granite Dam. The average distance traveled was 252 km and the average travel time was 38.7 d. For spring Chinook salmon, the average residence time was 8.7 min, and the maximum residency was 25.7 min. All spring Chinook salmon were from interior stocks and were released either above Rocky Reach Dam on the Columbia River or Lower Granite Dam on the Snake River. The average distance travelled was 878 km and the average travel time was 42.7 d. Two summer run steelhead also were detected at Russian Island. The steelhead residence time averaged 3.3 min and the maximum residency was 8.1 min. Both steelhead were from interior stocks, travelled an average distance of 1038 km, and had an average travel time of 18.1 d. One wild coho salmon was detected. It was released 51 km upstream of Russian Island and was detected 266 d after release. It remained in the detection channel for 81 min.

#### Woody Island

The Woody Island PIT detection array was constructed in 2011 and was operated from 21 March to 27 September. A total of 11 PIT tagged fish were detected: 8 Chinook salmon, 2 steelhead, and 1 coho salmon. Seven of the Chinook salmon were fall run fish and one was of unknown run type. Fall run Chinook salmon exhibited an average residence time of 3.6 h and the maximum residency was 13.7 h. All of the fall Chinook were released above Bonneville Dam and 43% were released above McNary Dam. The average distance travelled was 422 km and the average travel time was 28.5 d. The unknown run type Chinook salmon is likely a spring run fish based on its size at date of tagging. It had a short residence time of 29 seconds and had travelled 343

km in 4.3 d. Two summer run steelhead were detected at Woody Island and had an average residence time of 86.4 min and a maximum residency of 2.9 h. One hatchery coho salmon was also detected. It resided for 64 min and travelled 824 km in 60.7 days.

#### Wallace Island

The Wallace Island PIT detection array was constructed late in 2011, and operated from 4 August to 26 September. Two fish were detected; both northern pike minnow. The average residence time of the northern pike minnow was 1.5 d and the maximum residency was 3.1 d. The distance travelled of these fish cannot be determined because release information is provided at reach-level only.

#### Variation Among Sites

Fall run Chinook salmon (presumably subyearling) was the most prevalent life-history type detected at the Russian Island and Woody Island sites. The number of unique detections at Russian Island was nearly twice that of Woody Island, although the origins of detected fish were similar between the sites except that no fish released below Bonneville Dam were detected at Woody Island. Woody Island also had a higher percentage of detections of fish from interior stocks (originating above McNary Dam) compared with Russian Island (45% vs 30%), but the sample size was too small for this difference to be statistically significant.

Residence times at Russian were much higher than at Woody Island, which may be attributable to the greater habitat complexity and connectivity at Russian Island. Although the two sites are only 11 km apart, the habitat differences are distinct. Russian Island is composed of a complex network of intertidal channels and emergent marsh. The channels drain at low tide, and during high tide the marshes are inundated. Fish have greater access to the habitat via sheet flow over the marsh surface at high tides. After exiting the detection array at Russian Island juvenile salmon remain within a large marsh and channel network, which may encourage continued rearing in the vicinity and increase the probability of subsequent detections. In contrast, Woody Island lacks a complex network of intertidal channels, and the habitat is dominated by shrub-scrub vegetation. The detection array is located in an isolated channel with a single point of entry and egress. Individuals exiting the detection channel at Woody Island enter the the mainstem Columbia River, where maintaining position may be more difficult in the higher velocity currents.

**Objective 2. Determine stock-specific habitat use, life histories, and performance of juvenile salmon in key habitat complexes to fill data gaps in the tidal fluvial reaches of the estuary.**

*Task 2.1. Determine salmonid species composition and the temporal abundance, size distribution, and genetic composition of Chinook salmon occupying key shallow habitat complexes in Reach F*

During April, July, and September 2011, we conducted a series of reconnaissance surveys to select future sampling sites in the upper (UMC) and lower (LMC) ends of Multnomah Channel (Figure 12). Samples also were collected at our established main-stem, confluence, and back-water sites in reach E (to compare with LMC) and reach F (to compare with UMC) (Figure 12). Fish were collected with bag seines and fyke nets. Because of the highly variable river levels and associated variations in gear efficiencies, we could not directly compare fish abundances among sites and sampling dates. Tissue samples of juvenile Chinook salmon were collected at all sites for genetic stock identification as reported in Objective 1.

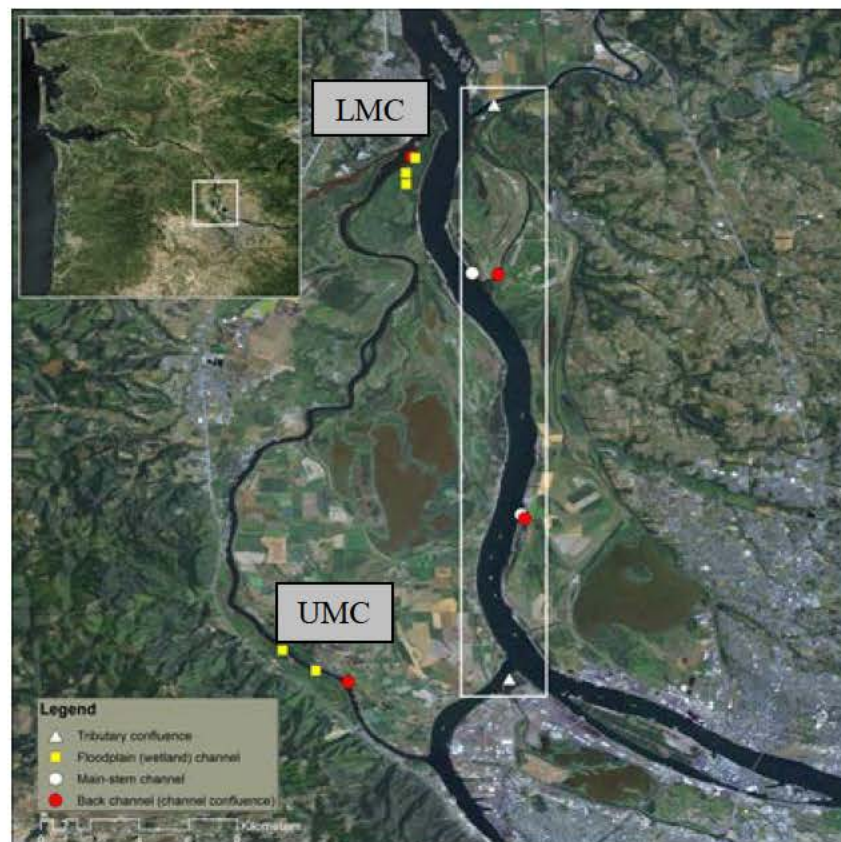


Figure 12. Upper (UMC) and Lower Multnomah Channel (LMC) survey sites during 2011. Sites in the white box correspond to reach E and F beach seining stations, including main-stem, back-channel, and confluence habitats.

## Results

Five salmon species were captured during the reconnaissance sampling, with Chinook salmon the most dominant (Table 2). Chinook salmon had a similar length-weight relationship regardless of sampling month or location, except in the lower Multnomah Channel area in July where they were heavier than main-stem Chinook of similar length (Figure 13). Most July LMC samples were collected on the forested floodplain during extreme high-water conditions. Genetic analysis indicates that during this period, a greater proportion of Upper Columbia River Summer/Fall stocks occupied the LMC site compared with the Reach E sites (Figure 14). The greater weight of LMC fingerlings could reflect differences in stock composition, increased feeding opportunities for juveniles on the inundated floodplain, or a combination of these effects. Fewer fry (<60 mm) were captured in the Multnomah Channel area than at the main-stem sites (Figure 13 and 14).

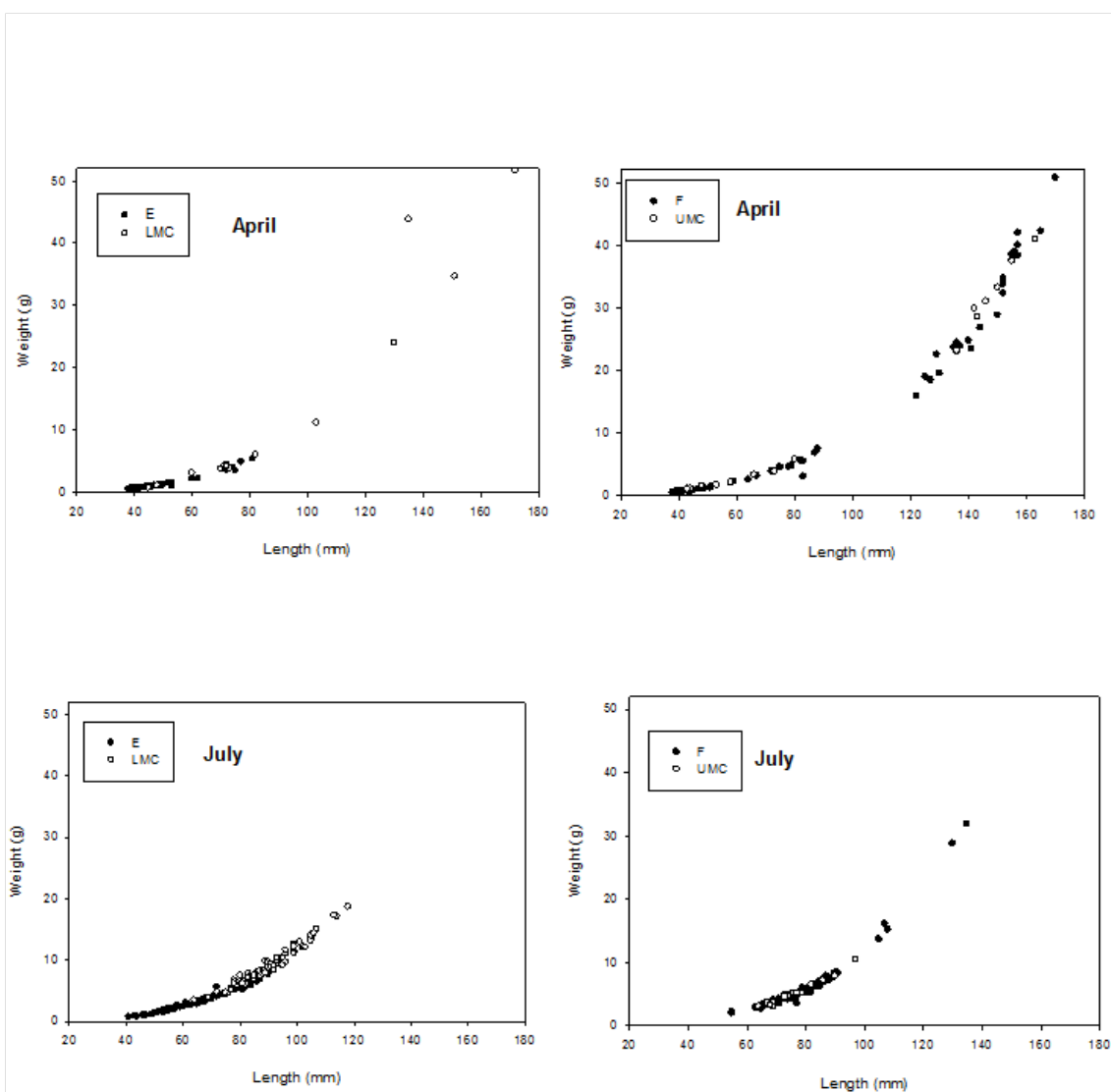


Figure 13 Length-weight comparisons of Chinook salmon captured in April and July 2011 in the Columbia River Reaches E and F and the upper (UMC) and lower (LMC) ends of Multnomah Channel.

Table 2. Summary of salmon catches and hatchery marks from stations in Reach E and F and the upper (UMC) and lower (LMC) ends of Multnomah Channel.

	April				July				September			
Species	LMC	E	UMC	F	LMC	E	UMC	F	LMC	E	UMC	F
<b>Chinook</b>	15	133	16	67	92	684	17	96	0	58	0	12
<b>% marked</b>	67	3	56	48	8	17	0	56		3		58
<b>Chum</b>		2		1								
<b>Coho</b>	2		54	1	1							
<b>Sockeye</b>		1										
<b>Steelhead</b>				3	1							

The percentage of marked hatchery Chinook salmon varied widely from 0 to 67% (Table 2). Low percentages of marked fish coincided with a high number of fry < 45 mm FL that comprised the total catch during several sampling periods. The proportion of marked fish in Reach F was fairly consistent for all three sampling months (48-58%).

We compared the genetic composition of juveniles collected in LMC (n=98) and UMC (n=33) with the composition of samples in reaches E (n=167) and F (n=157). Chinook salmon juveniles from Multnomah Channel were assigned to 8 of the 11 genetic stock groups in our analysis (Figures 14 & 15). In April, the largest contributors were WR Sp (n=16) and SCG F (n=8) stocks. WR Sp fish also were present in July samples (n=6), but UCR Su/F (n=61) and WC F (n=22) were more abundant. The proportion of UCR Su/F increased from April to July at both the Multnomah Channel and the Reach E and F sites (Figure 15).

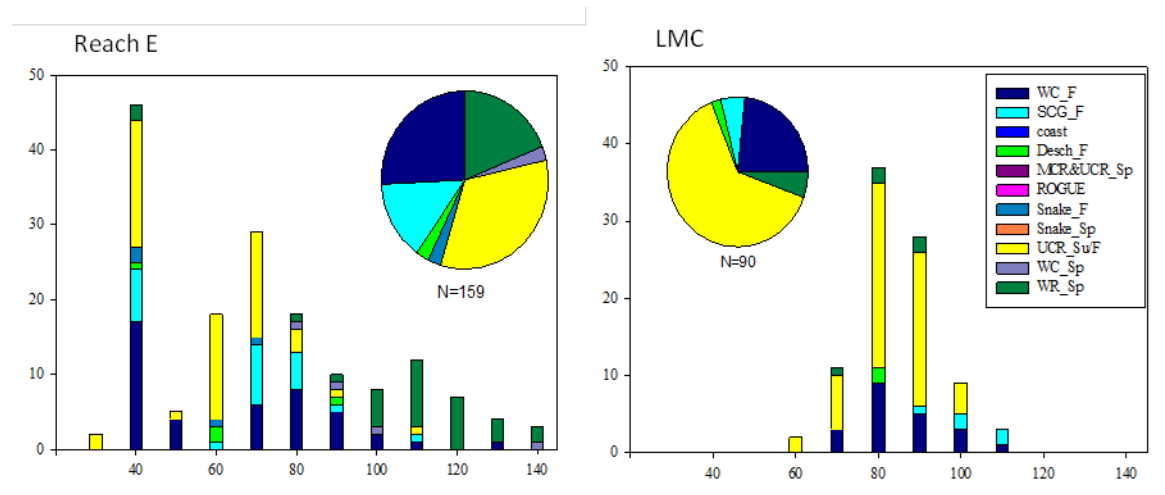


Figure 14. Genetic stock composition of Chinook salmon captured in the lower end of Multnomah Channel (LMC) in early July 2011. For comparison, data from Columbia River Reach E collected under Objective 1 are also shown.



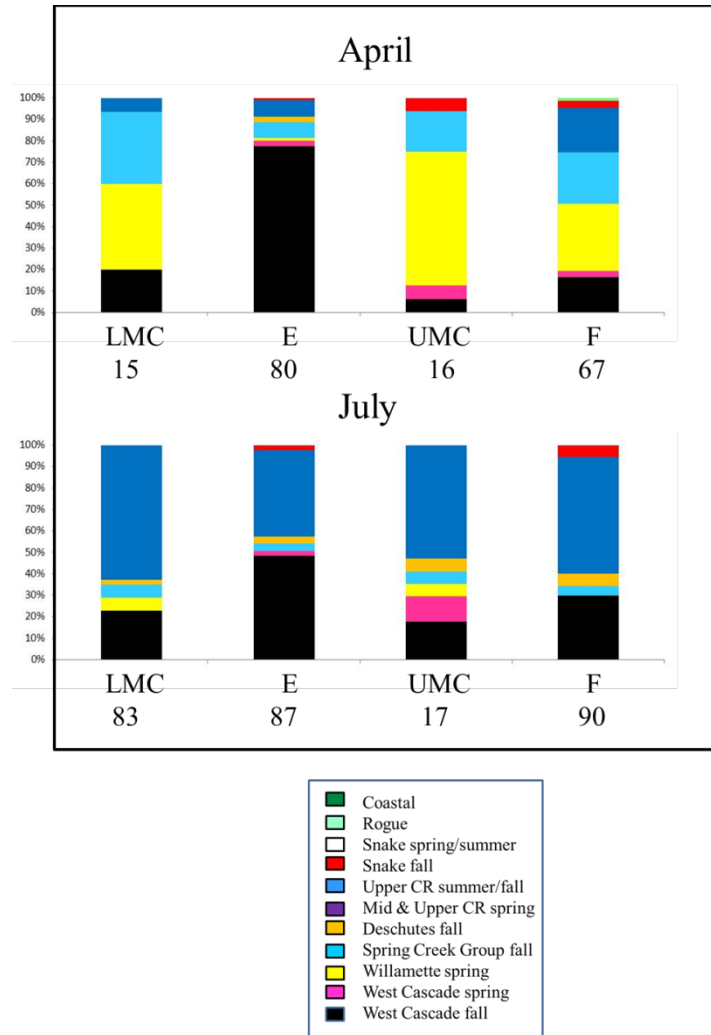


Figure 15. Proportions of individuals assigned to each of 11 stock groups in samples of Chinook salmon collected in Lower (LMC) and Upper Multnomah Channel (UMC) and in Reaches E and F (see Objective 1) during April and July 2011. Sample sizes are shown.

*Task 2.2. Monitor physical attributes (temperature, water depths, dissolved oxygen, etc.) of salmon habitats that influence rearing opportunities and performance.*

*Task 2.3. Estimate benthic prey and fall-out insect availability in selected Reach F habitats.*

*Task 2.4. Determine Chinook salmon diet composition and estimate diel consumption rates in selected reach F habitats.*

*Task 2.5. Determine growth rates, movements, and habitat-specific residency of juvenile Chinook salmon at selected PIT monitoring sites in wetland channel habitats.*

These tasks not scheduled for this project period.

**Objective 3: Monitor juvenile salmon life histories and their contributions to adult returns in selected estuary tributaries, including tributary examples where tidal habitats have been restored.**

**Objective 3a. Compare variations in the estuarine life histories contributing to the adult returns from multiple salmon ESUs**

*Task 3a.1. Reconstruct the juvenile life histories of returning adult Chinook salmon from a diversity of populations and ESUs. Identify key indicator populations for quantifying life history contributions to adult returns.*

In 2011-12 we analyzed adult otoliths Sr/Ca ratios with laser ablation inductively coupled plasma mass spectrometry (LAICPMS) to reconstruct the juvenile life histories that contribute to adult returns in selected Columbia River tributaries. We selected nine populations for analyzing adult otolith samples collected during spawning ground surveys in upper and lower Columbia River ESUs (Figure 16.). We have analyzed otolith samples for five populations of spring, summer and fall Chinook salmon from lower (Grays, Coweeman, and Lewis Rivers), main-stem (Hanford Reach), and upper (Methow) tributaries (n ~ 400 individuals).

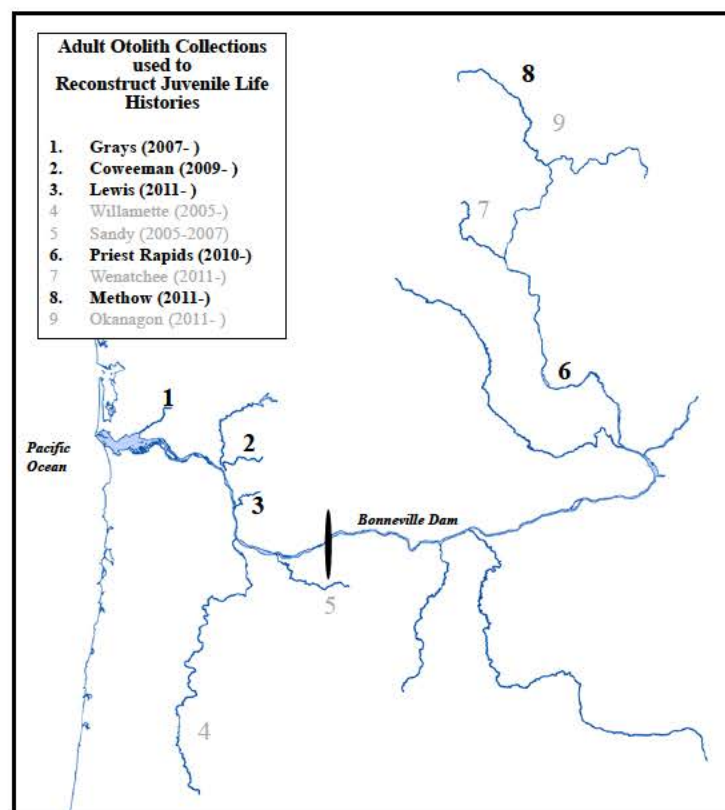


Figure 16. Location of adult otolith samples collected in selected main-stem and tributary sites of the Columbia River basin. Otoliths have been collected from nine sites and the otoliths from five of these sites (shown in dark bold) have been analyzed (map courtesy of Dale Gombert WDFW).

The preliminary results indicate that: (1) fry migrant (<60mm) life histories contribute to adult returns as far upriver as the Hanford Reach (Figure 17B), and (2) juvenile sizes at estuary/ocean entry vary among spawning populations (Figure 17; Table 3).

Table 3. Proportion of adult Chinook salmon returning to selected Columbia River populations based on size ranges at estuary/ocean entrance. Sizes were back-calculated from otolith Sr/Ca ratios.

	BC size at estuary/ocean entrance (mm)				n	Average	
	<60	61-90	91-120	>121		Fl (mm)	SD
Coweeman FCk 2009	0.01	0.42	0.51	0.06	106	94	15.43
Coweeman FCk 2010	0.00	0.29	0.59	0.12	41	100	14.74
NFK Lewis FCk 2011	<b>0.10</b>	0.27	0.56	0.08	52	95	23.72
Hanford Reach Su/FCk 2011	0.02	0.74	0.25	0.00	53	<b>82</b>	13.94
Methow SuCk 2011	0.00	0.06	0.64	0.30	49	116	21.14
Methow SpCK 2011	0.00	0.02	0.40	0.57	42	126	17.29

We found that some populations entered the estuary at a relatively large mean size as might be expected for yearling migrants from spring-spawning populations. However, given their close proximity to the estuary, we were surprised that the mean size at estuary entry among several lower Columbia River tributaries (Coweeman and North Fork Lewis) was larger than that of upper Columbia River summer/fall Chinook from the Hanford Reach, the only main-stem spawning population we examined (Figure 17). Spring Chinook from the Methow basin are predominantly yearling spring migrants, while summer Chinook are classified as subyearling migrants (WDFW scale analysis). Yet the size at estuary/ocean entrance of these two migration ages differed only slightly (~10 mm). The similar size at estuary/ocean entry may be due to: 1) increased growth rates for subyearling migrants that reside in habitats outside their natal streams, and/or 2) misclassification of “subyearlings” to include Chinook that leave their natal streams within a few months but still remain within the basin (i.e., between their natal tributaries and the estuary) for an entire year before migrating to salt water.

These preliminary results demonstrate the value of otolith reconstruction for comparing life history variations within and among Columbia River ESUs. Further work is needed to (1) evaluate juvenile life-history expression among adults for additional years and ages of return, (2) compare life-history expression among different Chinook races and spawning locations (i.e., main-stem, lower, or upper tributary etc.); and (3) contrast migration timing and residency of experimental populations from the main-stem and lower Columbia River.

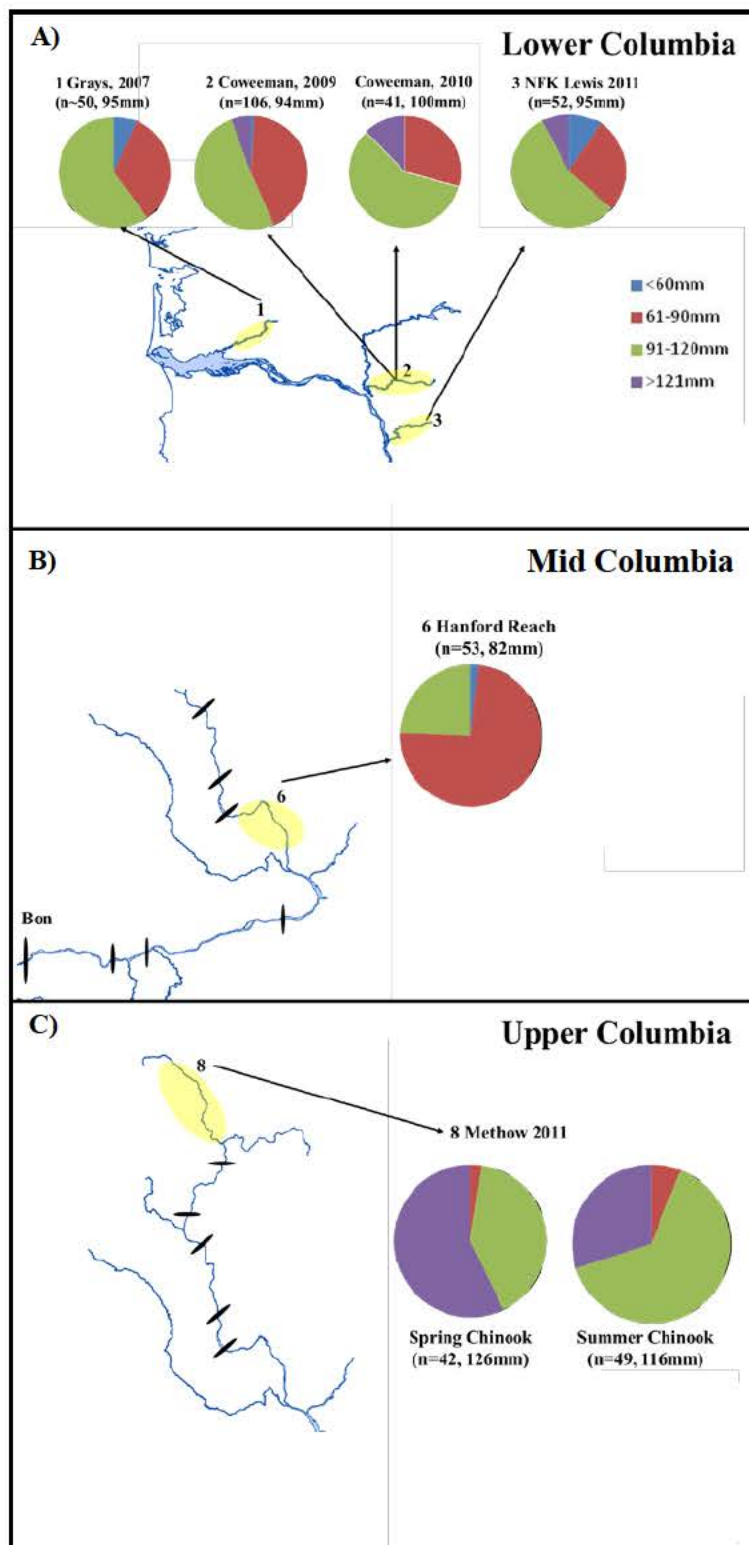


Figure 17. The location of returning adults and the proportion of juvenile life histories of each population based on size at estuary/ocean entrance in the lower (A), mid (B), and upper (C) Columbia River.



*Task 3a.2 Quantify the precision and accuracy of back calculating fish lengths and residence times from otolith microchemistry*

Otolith Sr/Ca has been widely used to reconstruct juvenile life histories in anadromous fishes including size at and timing of estuary/ocean entry. However, few studies have evaluated the accuracy of data derived from laser ablation inductively coupled plasma mass spectrometry (LAICPMS) to reconstruct juvenile life histories in salmonids. We used SrCl marked hatchery Chinook salmon of known size (91-93 mm fork length), and date at SrCl tagging to evaluate the accuracy of using otolith Sr/Ca inflection to estimate size.

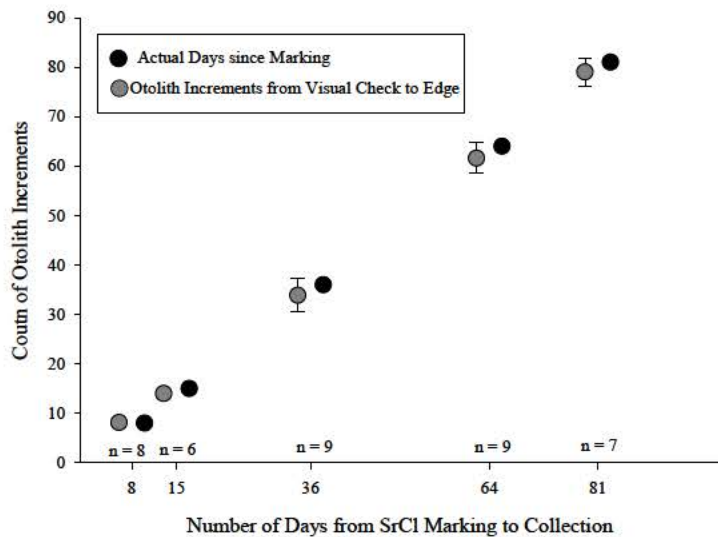


Figure 18. Comparison of otolith increments by the number of days since marking determined from visual check of SrCl marking (grey filled mean  $\pm$  SD) versus known number of days (black filled).

Since accurate size estimations require that distance to elemental marks from LAICPMS represent true otolith distance, we compared visual estimates of otolith radius at marking and total radius to those that were derived from LAICPMS. First, increment analysis indicated that SrCl marking was associated with a visual check that was consistent with the date of tagging and daily increment formation (Figure 18). This was further confirmed in three individuals (not shown) by the analysis of spot scans immediately before the check (low strontium) and on or immediately after the check (high strontium). Figure 19 indicates otolith radius at Sr/Ca inflection was smaller (16.6  $\mu$ m, median) than that determined by measuring along the laser scar to the visual check. Similarly, the total otolith radius determined from LAICPMS was smaller (25.2  $\mu$ m) than that derived from visual measurements. These results suggest that an underestimation of 17-25 microns may occur as a result of data processing and laser settings such as spot size or scan speed. Our next challenge is

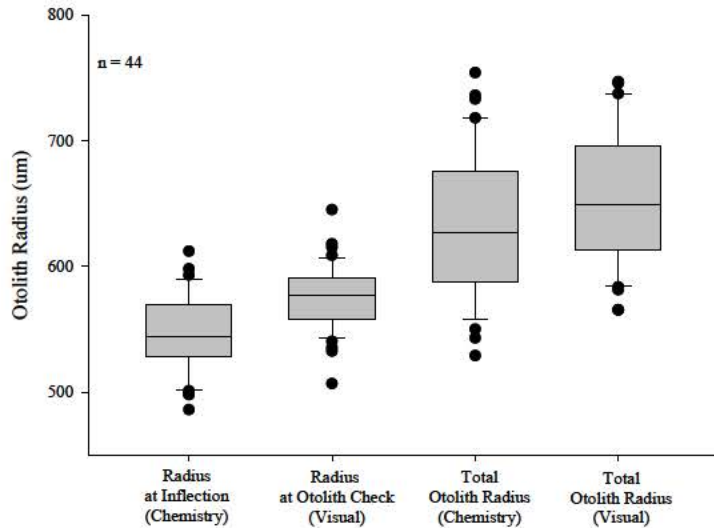


Figure 19. Comparison of estimated otolith radius at SrCl marking and total radius determined by chemistry and by visual otolith measurements along the laser scar.



to isolate the source of this underestimation and determine if this amount of error is biologically meaningful.

To estimate the accuracy of using otolith Sr/Ca to estimate size at marking, we compared known size at tagging to those determined from both the visual SrCl marking check and the Sr/Ca inflection using direct and proportional back calculation approaches. Figure 20 indicates that size was accurately estimated using the visual check, and Sr/Ca inflection using a linear relationship determined from this study ( $y = 0.1438x + 11.659$ ,  $R^2 = 0.7013$ ) and the proportional approach of Francis (1990). Linear relationships derived from other studies either underestimated fish size by an average of 10 mm at Sr/Ca inflection (Campbell 2010; Volk et al. 2010) or overestimated size at tagging by an average of 7 mm (Zabel et al. 2010). We hypothesize these differences are related to various biological attributes of each source population, for example, growth rate and rearing history or hatchery vs wild origin. Together these results suggest that otolith radius at Sr/Ca inflection determined from LAICPMS is useful for predicting fish size at and timing of estuary/ocean entrance but that the accuracy of directly calculating size estimates (often used for adult otoliths) may depend on stock- and stage-specific otolith radius to fish-length relationships.

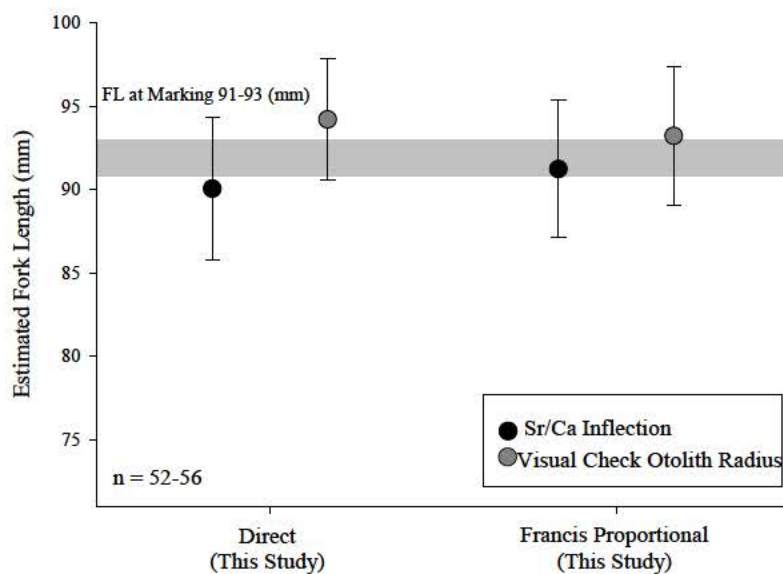


Figure 20. Estimated size (mean  $\pm$  SD) at SrCl marking determined by Sr/Ca inflection (black filled) and a visual check (grey filled). The grey box denotes known size (91-93mm) at SrCl marking.

*Task 3a.3. Review juvenile outmigrant, adult return, and life history data from existing ODFW and WDFW monitoring programs in tributaries below Bonneville Dam to identify suitable populations for experimental life history studies (Objective 3b).*

*Task 3a.4. Determine interannual variations in the size and time of estuary/ocean entrance and the relative contributions of diverse juvenile life histories to adults returning to each indicator population.*

These tasks not scheduled for this project period.

**Objective 3b. Conduct experimental marking and recapture studies in one or more estuary tributaries to identify tidal-fresh habitat associations, quantify the life histories of juvenile outmigrants, and estimate the estuary's contribution to adult returns.**

No tasks for this subobjective scheduled before 2014.

**Objective 4: Use life-cycle modeling to evaluate estuary restoration needs for recovery of all salmon ESUs and to account for projected effects of climate change.**

*Task 4a. Life cycle modeling: Evaluate the potential response of selected salmon ESUs from improvements to estuary rearing opportunities and salmon performance.*

Life-cycle modeling conducted in 2011 was based on year-1 results of the stock distribution survey (Objective 1). An important capability of the modeling effort will be to explicitly account for climate change in the evaluation of restoration responses.

*Task 4a.1. Incorporate an estuary component into existing life cycle models and expand modeling to other ESUs to assess population sensitivities to estuary survival gains*

#### Model modifications

We modified existing life cycle models (Zabel et al. 2006, Interior Columbia TRT and Zabel 2007) to include an explicit survival through the estuary. Previous versions of the model represented third year survival,  $S_3$ , to include both survival through the estuary and survival during the first year in the ocean. In the latest version, we represented  $S_3$  as

$$S_3 = S_{est} \cdot S_{O1},$$

where  $S_{est}$  is survival through the estuary and  $S_{O1}$  is survival during the first year in the ocean.

In prospective modeling, we modeled  $S_3$  as a function of several ocean indicators that varied annually, for example as functions of the Pacific Decadal Oscillation (PDO) or upwelling intensity. We predicted  $S_3$  annually based on historical time series of the ocean indicators and we represented the uncertainty in the underlying relationships by including an error term. Several scenarios of future ocean conditions were modeled by sampling various periods of the time series reflecting poor, recent, or good conditions (Zabel et al. 2006; Interior Columbia TRT and Zabel 2007).

This functionality was maintained in the updated version of the model by assuming the variability in  $S_3$  occurred in the ocean and that survival through the estuary was constant from year to year:

$$S_{O1}(t) = S_3(t) / S_{est}$$

The assumption about constant survival through the estuary will be reparameterized at a later time.

### Application: sensitivity analysis for Snake River spring/summer Chinook.

We applied the updated model to several populations of Snake River spring/summer Chinook salmon: Catherine Creek (OR), Marsh Creek (ID), and South Fork Salmon River (ID) (see ICTRT and Zabel 2007 for details of the population models). We set  $S_{est} = 0.84$  based on a study that estimated survival from river km 153 to the mouth using JSATS acoustic tags (McMichael et al. 2011).

To conduct the sensitivity analysis, we increased  $S_{est}$  additively by the following increments: 0%, 2%, 4%, 6%, 8% and 10% (i.e.,  $S_{est}$  ranging from 0.84 to 0.94). We also considered two climate scenarios: poor ocean conditions (1977-1997) and recent ocean conditions (1980-2001). The model was run for 50 years, with initial population densities set to those used in ICTRT and Zabel (2007).

The sensitivity analyses (Figure 21) demonstrate that small increases in survival through the estuary generated marked improvements in population viability. For instance, under “recent” ocean conditions, a 4% increase in estuary survival increased mean abundance by 12.6%, 6.2%, and 8.1% in Catherine Creek, Marsh Creek, and South Fork Salmon River, respectively. The increase in survival also decreased the probability of extinction. Increasing survival in the estuary by 4%, for example, decreased probability of extinction in Marsh Creek from 37% to 34%.

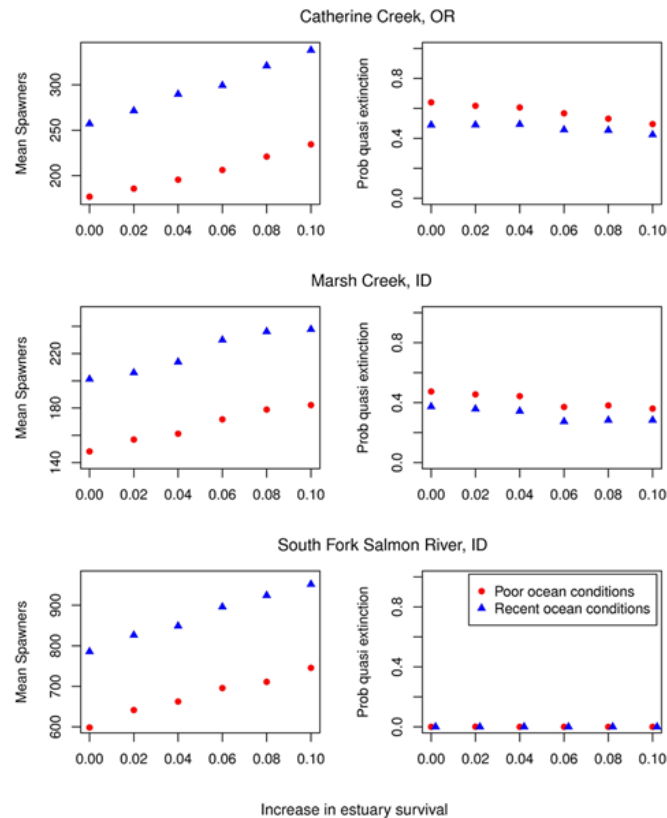


Figure 21. Sensitivity analysis demonstrating the effect of increasing estuary survival on mean spawner abundance and probability of extinction for three populations of Snake River spring/summer Chinook salmon. The sensitivity analysis was conducted for two assumptions on future ocean conditions.

This sensitivity analysis is intended to produce estimates of the type of population viability improvements expected in response to improvements in survival through the estuary. The next challenge is to relate increases in survival to mitigation actions in the estuary.

*Task 4a.2. Conduct a modeling workshop to review results of the other research objectives and incorporate estuary performance parameters into the life-cycle models*

On February 29 – March 1, 2012 we conducted a modeling workshop to explore approaches for linking habitat restoration and other estuary management actions to salmon population viability. The workshop explored the strengths and weaknesses of the hydrological (Objective 4b) and life-cycle (Objective 4a) models and discussed alternative modeling approaches to account for estuary influences on salmon populations. The workshop addressed three primary objectives:

1. Evaluate the data needs and capabilities of the salmon habitat-opportunity and life-cycle models.
2. Explore methods for integrating habitat-opportunity and life-cycle models to assess the contributions of selected estuary habitats and landscapes to salmon population viability and recovery.
3. Discuss ways to improve the models and translate restoration or other estuary management actions into changes in population viability and fitness.

Independent results of the hydrological and life-cycle models were reviewed the first day of the workshop and are briefly summarized in Tasks 4.b.3 and 4.a.1, respectively. On day 2, the workshop participants discussed methods for directly assessing estuary survival or for measuring biological “surrogates” that may be linked to survival and could be incorporated into life-cycle models, including salmon residency and growth; stock-specific habitat opportunities and bioenergetics; and life-history diversity. We reviewed management questions and key environmental or restoration scenarios for the models to evaluate. The workshop identified a series of subsequent actions to support modeling efforts and to assess the effects of estuary management actions on population viability, including the following:

- Review the status of knowledge for relating estuary growth to salmon survival, and assess the adequacy of existing growth, residency, and survival data to test this relationship in the Columbia River estuary.
- Develop a working paper for estimating habitat capacity and testing alternative capacity hypotheses, including the survival:growth relationship.
- Establish a comparative method for understanding population responses to changing conditions by contrasting highly successful and relatively unsuccessful populations.
- Develop potential “rules” for fish movements through estuary landscapes that could be incorporated into habitat-opportunity models. Select relevant modeling scenarios based on these rules.

- Compare salmon habitat opportunities among different genetic stock groups with different points of entry to the estuary. Evaluate hypotheses of population performance based on potential habitat and growth opportunities along the estuary pathways of each stock.
- Prepare a narrative of potential management scenarios (actions, expected outcomes, how we will model, etc) to be tested through modeling. Superimpose climatic changes on each scenario to evaluate population viability. The narrative should include explicit hypotheses of expected biological response.

*Task 4a.3. Model expected life-cycle benefits from estuary restoration targeting at-risk salmon stocks.*

Not scheduled during this period.

**Objective 4b Hydrological modeling: Model the dynamics of stock-specific habitat opportunities in the tidal-fluvial estuary in response to changing flow, temperature, and climate conditions.**

Hydrological modeling to date has concentrated on linking salmon habitat opportunity to regional climate, flow regulation, and changes in bathymetry (Bottom et al 2005; Burla et al. 2007; 2010). We used high-resolution numerical simulations of circulation that are filtered through criteria based on physical state variables believed to influence the opportunity of access of salmonids to estuarine and tidal freshwater habitat. State variables include flow, temperature, salinity, and bathymetry, and scenarios exploring changes of these variables in response to climate change are being developed. Progress was made improving the skill of representation of circulation within CMOP's modeling system, the Virtual Columbia River (VCR), to the dynamics of stock-specific habitat opportunities. The present project adds to this foundational framework.

Goals for this reporting period include:

- Expand and refine the domain of the VCR circulation model to (a) include all hydrogeomorphic reaches of the Columbia River estuary ecosystem classification, and (b) refine the representation of target habitats within those reaches.
- Assess and improve the skill of the expanded-domain VCR circulation model, system-wide and at multiple spatial scales within hydrogeomorphic reach F.
- Model the dynamics of salmon habitat opportunity across all hydrogeomorphic reaches to support life-cycle modeling
- Simulate effects of climate change scenarios on estuarine habitat opportunities for selected salmon Evolutionarily Significant Units (ESUs).

We report here on progress in four inter-related tasks.



*Task 4b.1. Extend and refine the computational grid*

We extended the Virtual Columbia River to include regions upstream of Beaver Army, which previously served as ‘river boundary’ for the domain. Specifically, the model domain of computational grid 26 (Figure 22) now extends upstream to the Bonneville Dam (in the Columbia River) and to the Willamette Falls (in the Willamette River). Spatial refinement varies strongly from river-to-ocean, a process facilitated by the use of unstructured triangular grids.

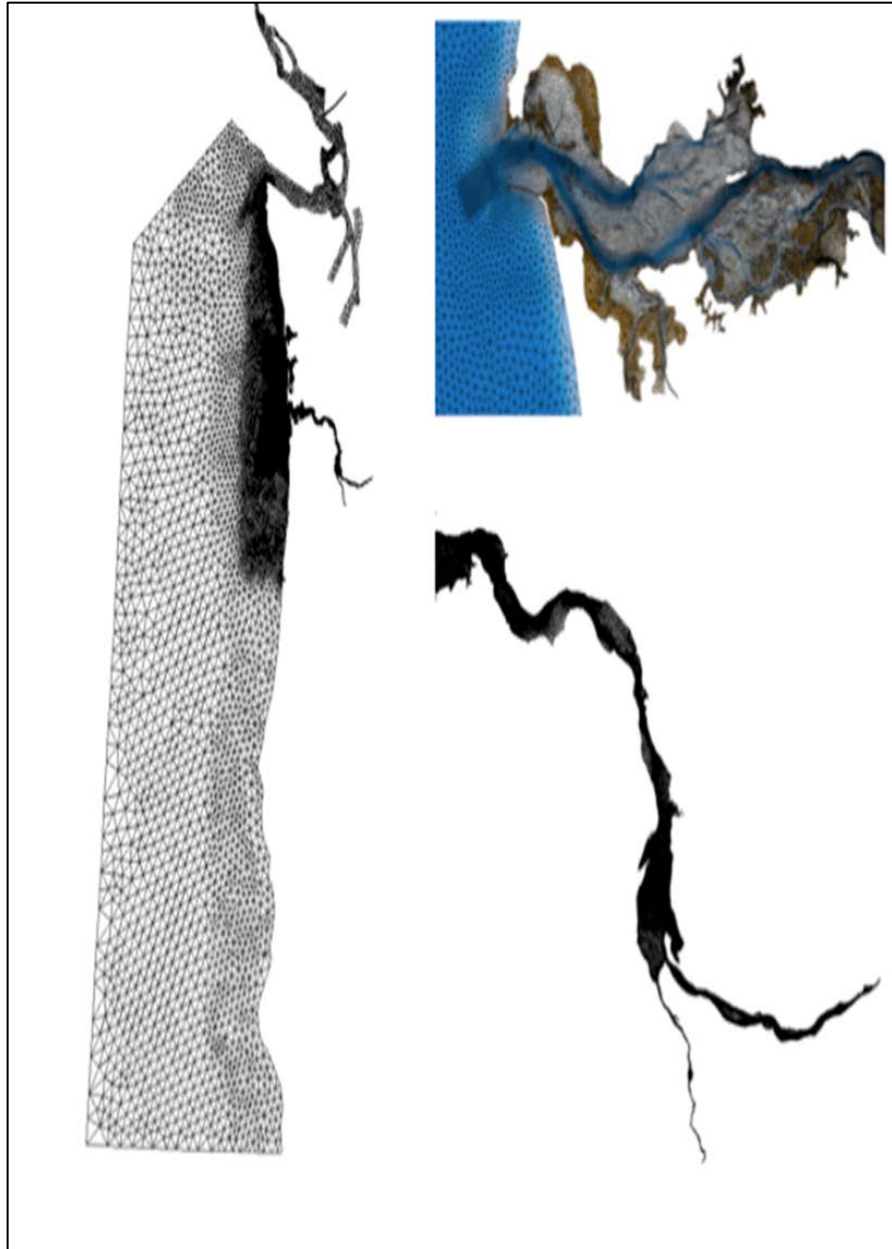


Figure 22. The computational grid 26 (left) includes the continental shelf of Oregon and Washington, with higher refinement in the lower estuary (top right) and tidal freshwater (bottom right).

As implied by the number 26, the Virtual Columbia River has employed multiple generations of computational grids. The adjustment of these grids over time is strategic, either to improve computational skill (an iterative process, see Task 4b.2) or to capture previously unrepresented scales of interest

The generation of decade-scale circulation simulations to support the modeling of habitat opportunity (Section 4.3) takes two or more months to complete (depending on the computational resources allocated), and requires “freezing” the computational grid. We began generating the circulation simulation DB26 (with grid 26), and completed a full year (year 2000). Skill assessment of DB26 for 2000 did not, however, meet our target skill criteria for representation of water levels (which require errors less than 30 cm in absolute value), in particular in and upstream of the area of the confluence of the Columbia and Willamette rivers.

The process of improving water levels (Section 4.2) led to a decision to adjustments in grid 26. After several iterations between grid adjustments and model calibration, we are converging on a computational grid that meets our skill targets. This grid (grid 29) should be finalized in August 2012, allowing for the associated simulation database (DB29) to be created; the expected completion date for DB29 is the end of calendar year 2012.

*Task 4b.2. Calibrate the model and validate simulations of circulation system-wide and at multiple scales within in reach F.*

A significant development this past year was to identify and find ways to remedy the causes for systemic under-prediction of water levels in the Willamette River and the Columbia River above Beaver Army and particularly above the confluence of the Willamette River. That process of calibration is highly iterative and involves changes in the computational grid as well as multiple input parameters to the model. This process is now nearing completion, and a publication is in preparation (for submission to a peer-reviewed journal) that describes the calibration process and its outcomes.

In particular, the solution for skill improvement that was derived from the calibration process involves the following elements, with steps 1 and 2 the most critical:

1. a change in boundary conditions at Bonneville Dam, with both discharges and water levels imposed (versus the more traditional imposition of discharges only);
2. the refinement of the Willamette River grid, to better describe flow propagation in this very highly dissipative tributary; inclusion of the discharges of the Clackamas, Lewis, and Cowlitz rivers, which, although small relative to the discharges at the Willamette Falls and Bonneville Dam, appear to have enough local significance to require explicit representation.

Figures 24 and 25 illustrate results for a benchmark period (24 September to 31 December 2007, for which river discharges are shown in Figure 23), for one of the intermediate calibration simulations (Run 14). This model run met the target skill criteria for water levels in average for the period, and also represented minimum water levels within the skill criteria (Figure 24); however, maximum water levels were under-predicted by more than 30 cm.

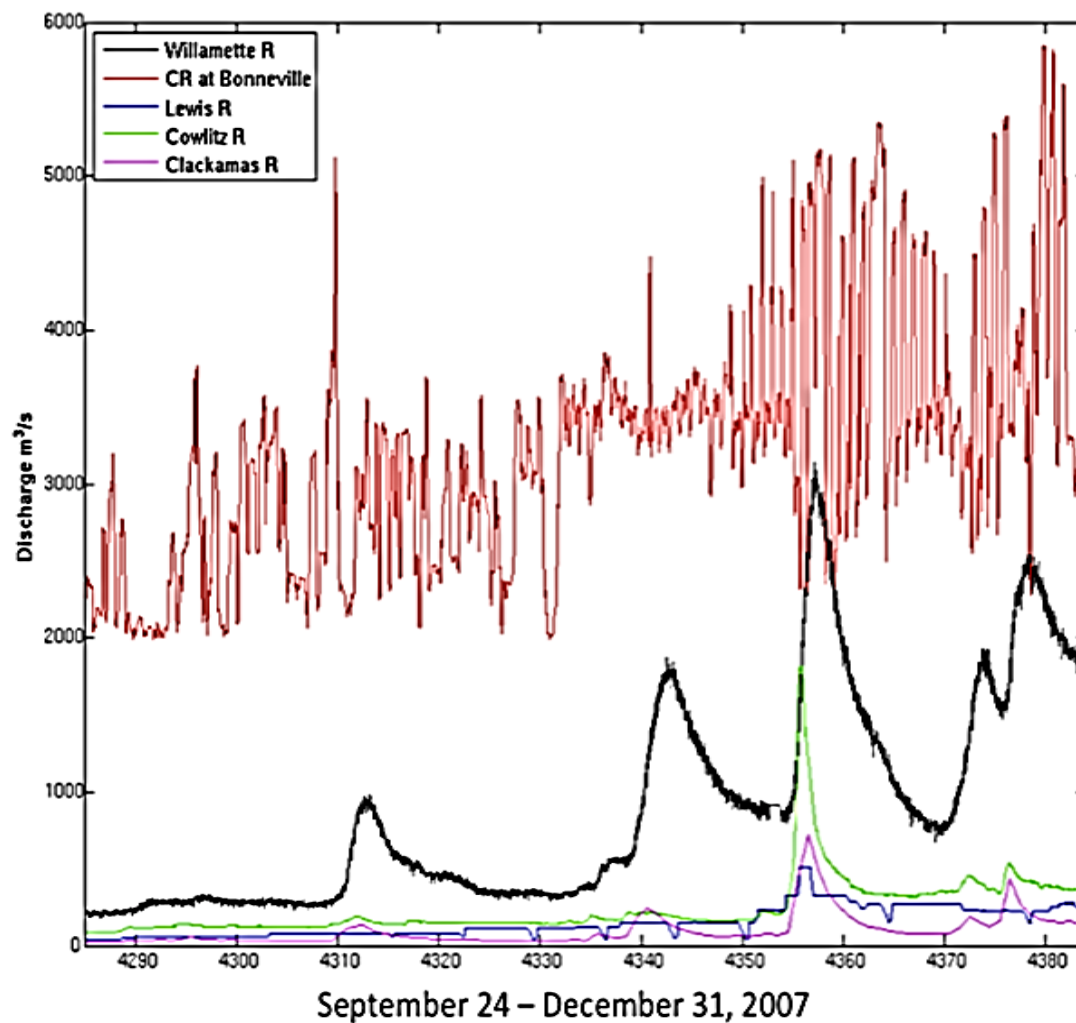


Figure 23. River discharges at Bonneville Dam and various tributaries (Willamette, Clackamas, Cowlitz and Lewis rivers) for one of the reference periods used in the calibration process that is informing the evolution from DB26 to DB29. Of note are the various peak flows at Willamette Falls, which are computationally challenging – and therefore a good reference for calibration studies.

Figure 24 shows that under-predictions of the maximum water levels are primarily associated with a peak flow in the Willamette River, which prompted the detailed analysis of energy levels (and the eventual local rebuilding of the grid) for this tributary.

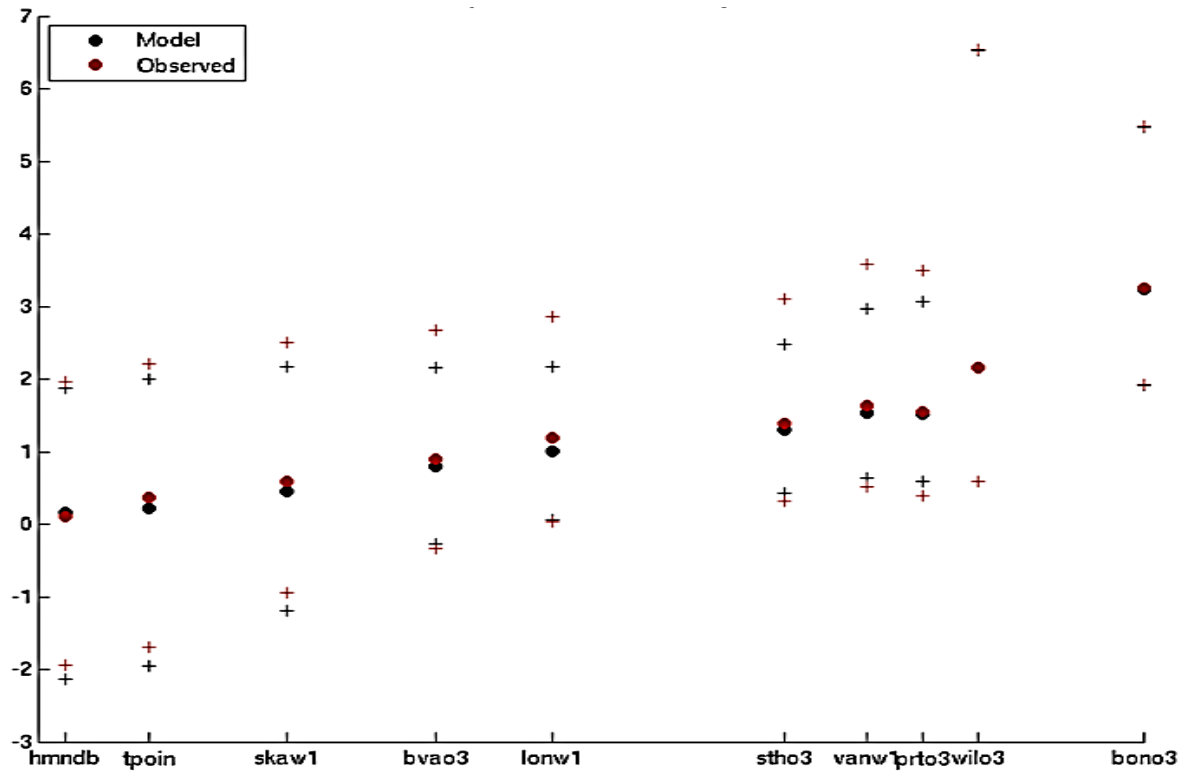


Figure 24. Water levels (average, circles; maxima and minima, crosses) in meters NGVD29 for a sub-period within September 24-December 31, 2007 at tidal gauges along the Columbia River (lower estuary to the left; Bonneville Dam to the right). Data shown are from observations (red) and from one of the simulations (Run14; black) of the calibration process. Averages and minima show good modeling skill, but maxima indicate that the largest peak flow at the Willamette Falls (previous figure) is not well captured (see also next figure). Station acronyms are as follows (all stations are from NOAA, except hmndb, which is a CMOP station). hmndb: Hammond Basin. tpoin: Tongue Point. skaw1: Skamakwa. bva03: Beaver Army. lonw1: Longview. stho3: St. Helens. vanw1: Vancouver. prt03: Portland (Morrison Bridge; Willamette River). wilo3: Willamette Falls (Willamette River). bono3: Bonneville Dam.

A similar (but more streamlined) process of calibration is being used to improve the skill of the circulation simulations in the Cunningham Slough. Multi-month data collected in 2012 at three stations in the slough is serving as reference.

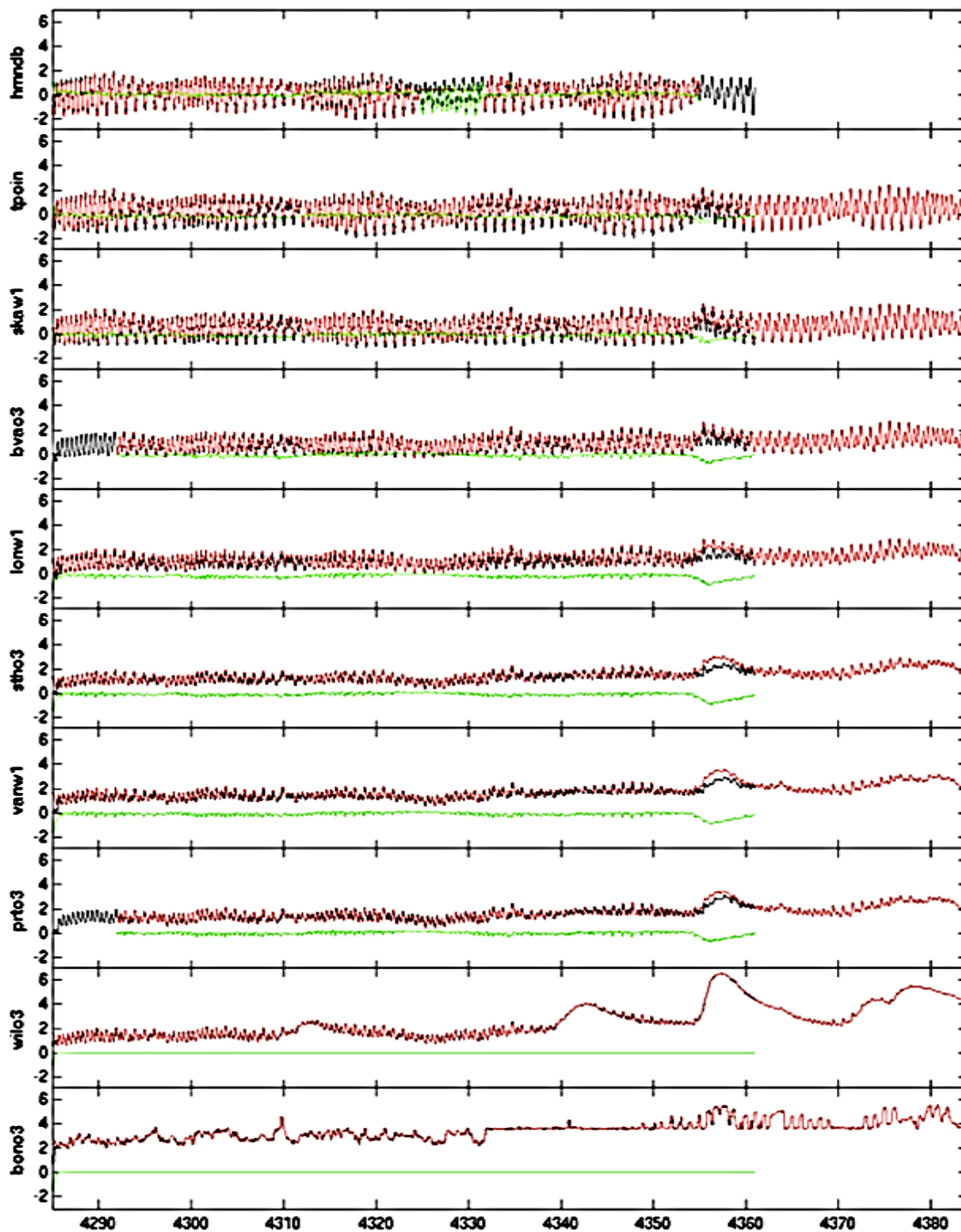


Figure 25. Time series of water levels (in meters NGVD29, for a sub-period within September 24-December 31, 2007) at tidal gauges along the Columbia River (lower estuary to the top; Bonneville Dam to the bottom). Data shown are from observations (red) and from one of the simulations (Run14; black) of the calibration process. Differences are in green. Results illustrate the point made in the caption of the previous figure. Both this and the previous figure show automated products, not aesthetically optimized. Station acronyms given in Figure 24



*Task 4b.3. Model the dynamics of salmon habitat opportunity*

While the skill of simulation database DB26 was being improved (Task 4.2), we used the 2002 results to explore methodologies addressing several important questions related to the modeling of salmon habitat opportunity. Early results were presented in the Salmon Modeling Workshop described above.

Habitat opportunity criteria relate to various circulation variables. Namely, favorable habitat opportunity is currently defined as

Depth:  $0.5 < D < 2$  m

Velocity:  $V < 25$  cm/s

Temperature:  $T < 19^{\circ}\text{C}$

Salinity:  $S < 5$  psu

A limitation of the above approach is that the various physical criteria respond distinctly to external forcing, making the analysis habitat-opportunity responses to natural and induced variability complex. We therefore explored methods for aggregating habitat-opportunity indices that would complement results derived from each individual criterion. Our initial aggregation approach anchors the existence of favorable habitat to the depth criterion (i.e., based on “where fish are found”), and ranks habitat based on how many of the other 3 criteria are also met within areas of satisfactory depth.

Using the aggregated criteria, we developed methodological approaches that lend insights into the habitat opportunity in the estuary. Selected examples:

- We identified “corridors” of habitat opportunity, across all hydrogeomorphic reaches of the estuary (Figure 26). “Bottlenecks” of opportunity can be seen at multiple spatial scales, and the degree of the bottleneck can also be visualized.

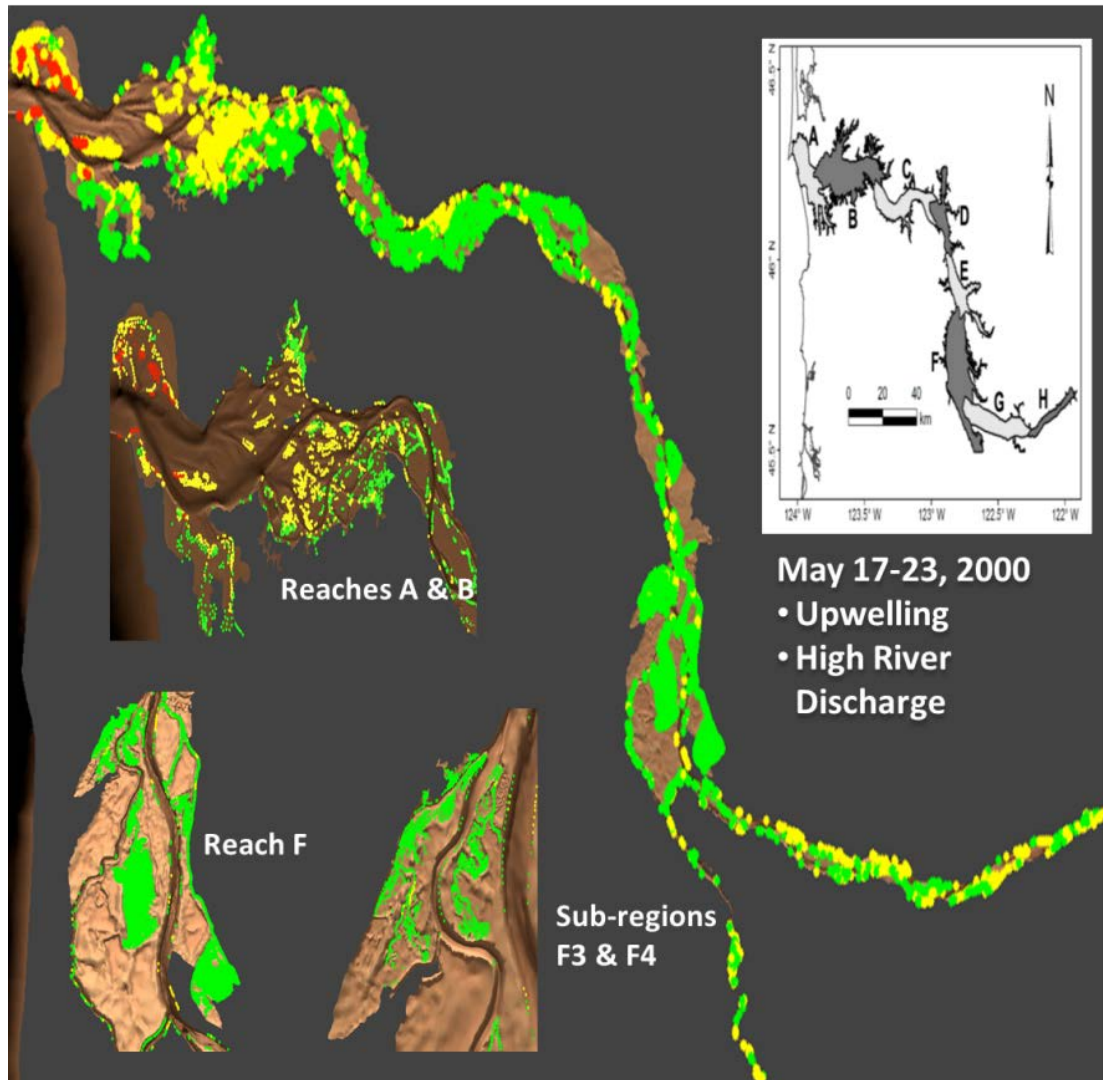


Figure 26. Example of corridors of favorable habitat opportunity, for a week with high river discharge and sustained coastal upwelling, shown both system-wide and in zoomed form for Reach F and for Scappoose Bay - Cunningham Slough. Dots represent elements where all four individual criteria are met (green) or where the depth criterion and two other criteria (yellow) or one other criterion (red) are met for 25% or more of the time over the week. Note that results are based on simulation DB26. We expect results based on DB29 to show substantially different (likely higher) habitat opportunity in reach F.

- We identified differences in driving mechanisms and in seasonal patterns of variation of habitat opportunity within and across hydrogeomorphic reaches (e.g., Figure 27).

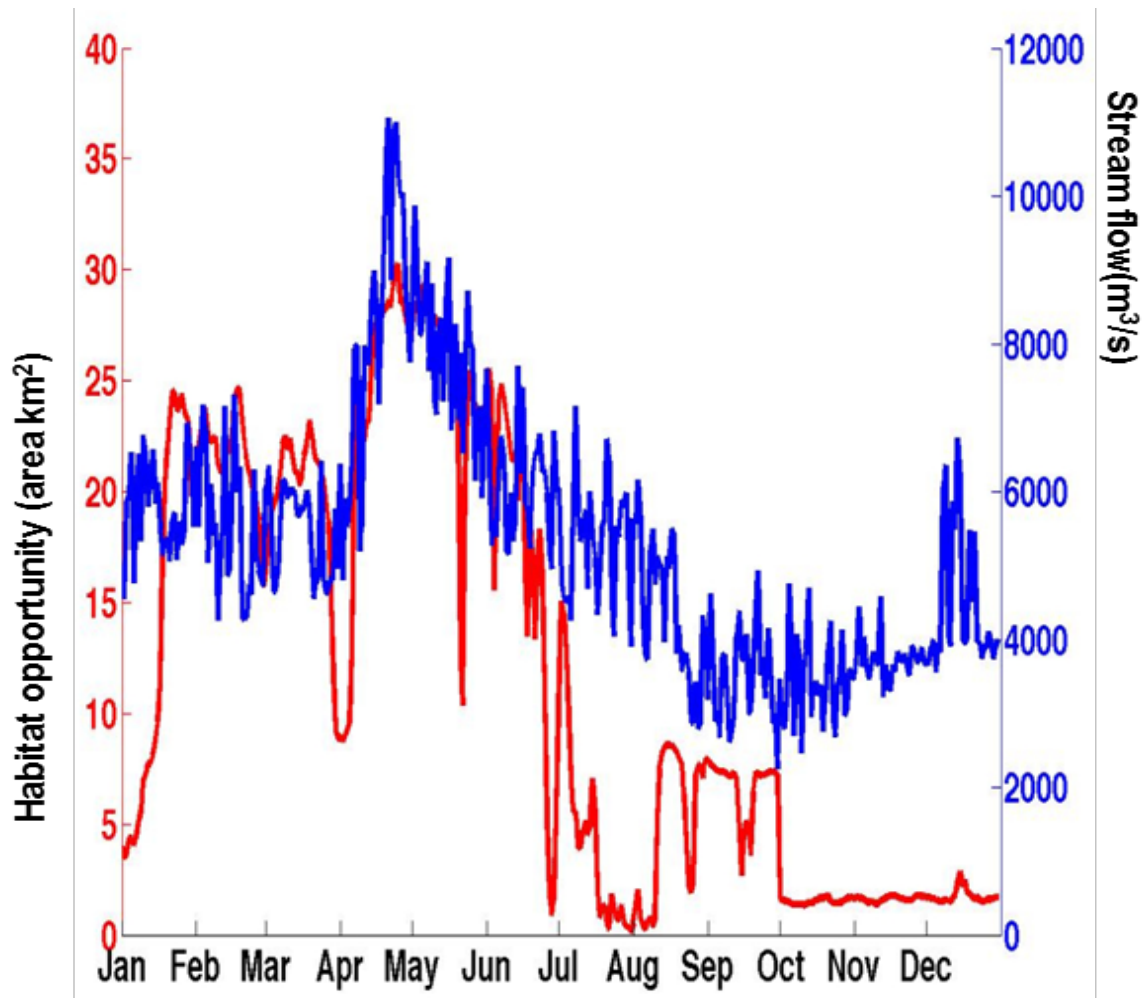


Figure 27. River discharge (blue) correlates visually with habitat opportunity (red) in Reach F (as defined here by all individual criteria being met). However, other factors are also important (e.g., the temperature criterion is responsible for the sharp decrease in habitat opportunity in July and August).

- We identified thresholds of response of habitat opportunity to external forcing, and began exploring their sensitivity to change in that forcing (Figure 28).

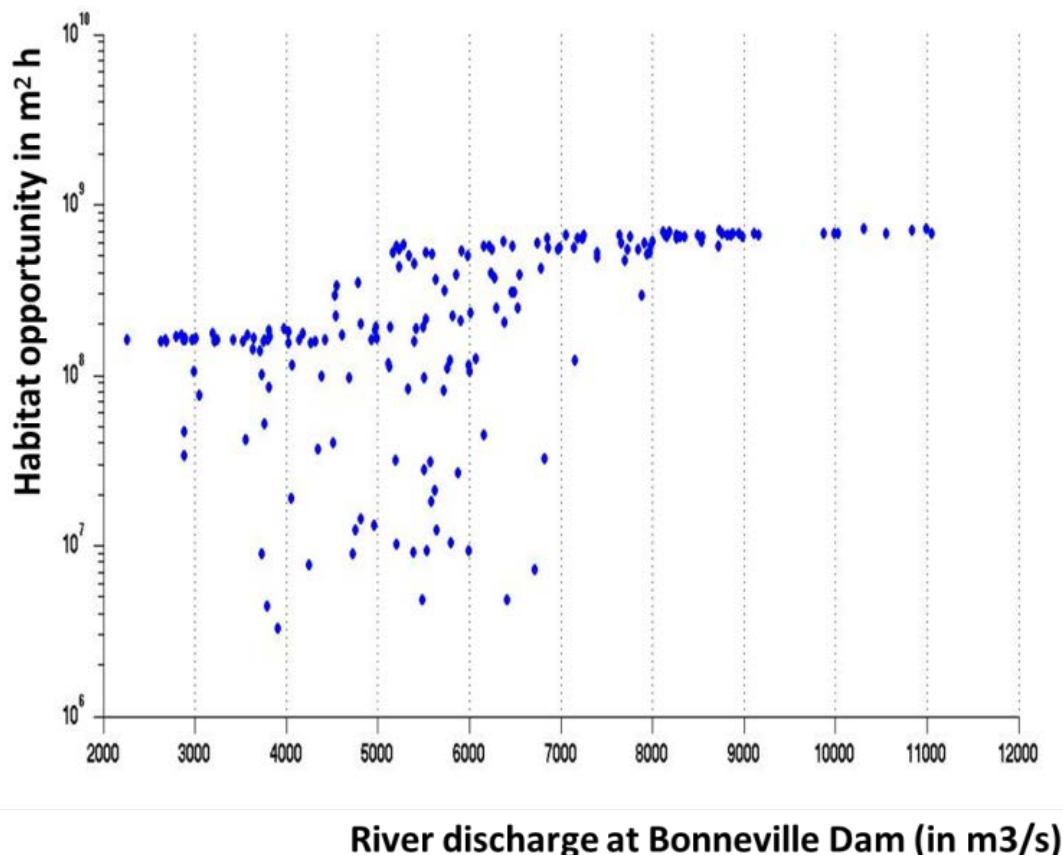


Figure 28. The response of estuarine habitat opportunity to river discharge (as illustrated here for reach F) appears to be distinctly different for discharges below and above a threshold of  $\sim 7,000 \text{ m}^3/\text{s}$ , based on increased scatter at lower flows.

We have historically used the habitat opportunity criteria in reference to “subyearling Chinook salmon,” without accounting for important differentiating factors such as stocks, size classes, and other population characteristics. In a first attempt at this differentiation (Figure 29), we defined and used criteria for 3 size classes (A: 40 mm; B: 60 mm; C: 80 mm):

- Depth: A)  $0.5 < D < 2 \text{ m}$       B)  $0.5 < D < 3 \text{ m}$       C)  $0.5 < D < 4 \text{ m}$
- Velocity: A)  $V < 25 \text{ cm/s}$       B)  $V < 43 \text{ cm/s}$       C)  $V < 60 \text{ cm/s}$
- Temperature:  $T < 19 \text{ C}$  (all classes)
- Salinity:  $S < 5 \text{ psu}$  (all classes)

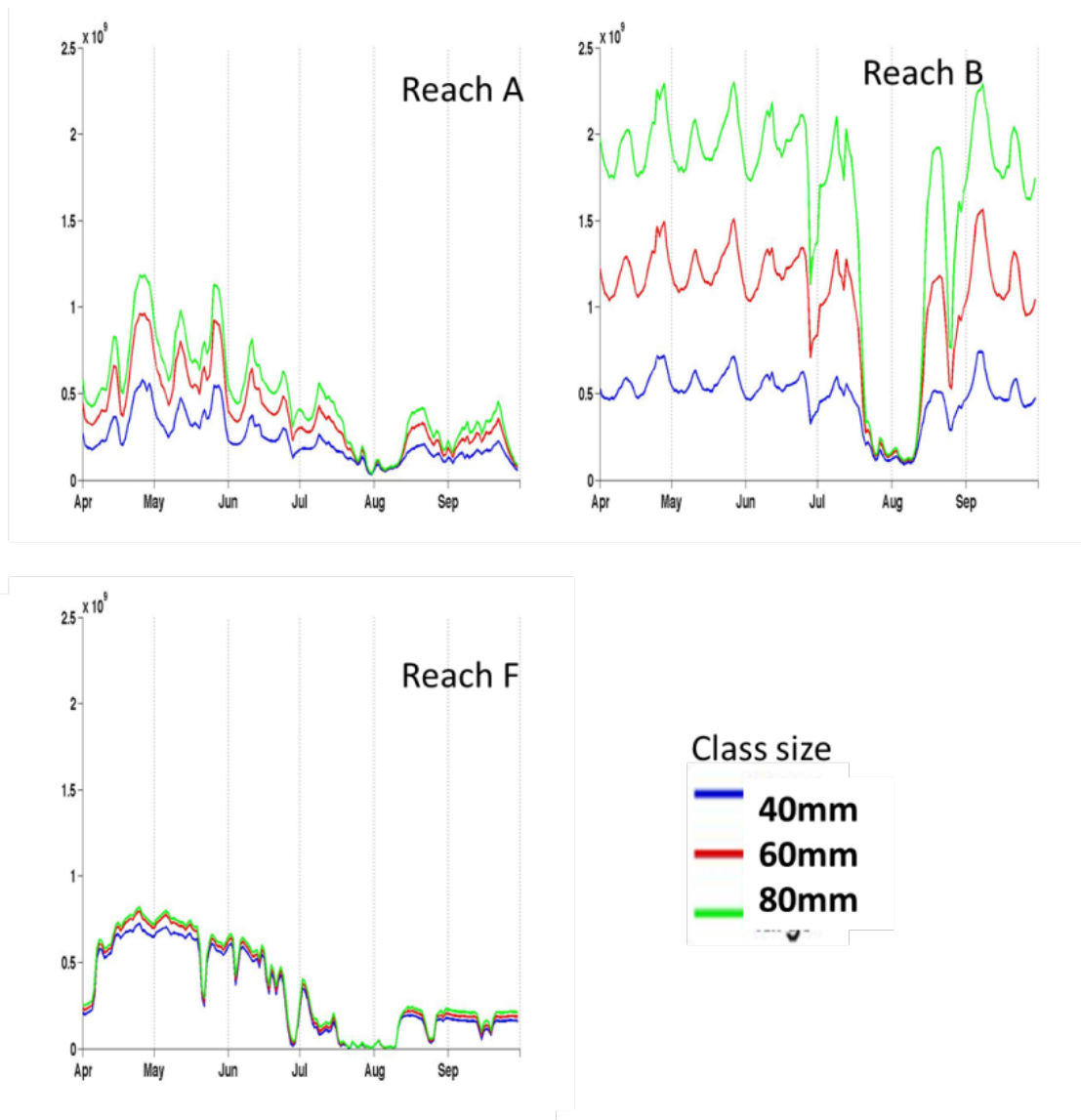


Figure 29. Results based on DB26 suggest strong sensitivity of habitat opportunity to salmon class size in some reaches (e.g., reach B) and minimal sensitivity in others (e.g., reach F). In reaches where class size makes a significant difference, larger size tends to equate with higher opportunity. The dip in the habitat opportunity in July/August (observed for all class sizes) is driven by the temperature criterion.

We note that all results shown in Figures 26-29 are based on circulation database DB26. Because DB26 under-predicts water levels in the tidal freshwater of the estuary, we consider these results illustrative only. Once DB29 is complete, a more systemic analysis of the spatial and temporal variability of habitat opportunity in the contemporary estuary will be conducted, with a higher degree of confidence in the modeling skill.



*Task 4b.4. Simulate effects of climate change scenarios on estuarine habitat opportunities for selected salmon ESUs.*

Using DB16 simulations for the contemporary Columbia River as a reference, we began assessing the impacts of climate change on habitat opportunity. The focus was on sea level rise, with three scenarios considered (30, 70 and 130 cm). Results show that sea level change influences habitat opportunity in the estuary, much through the influence on salinity intrusion length (Figure 30). This influence is felt both in terms of averages and of statistics (not shown).

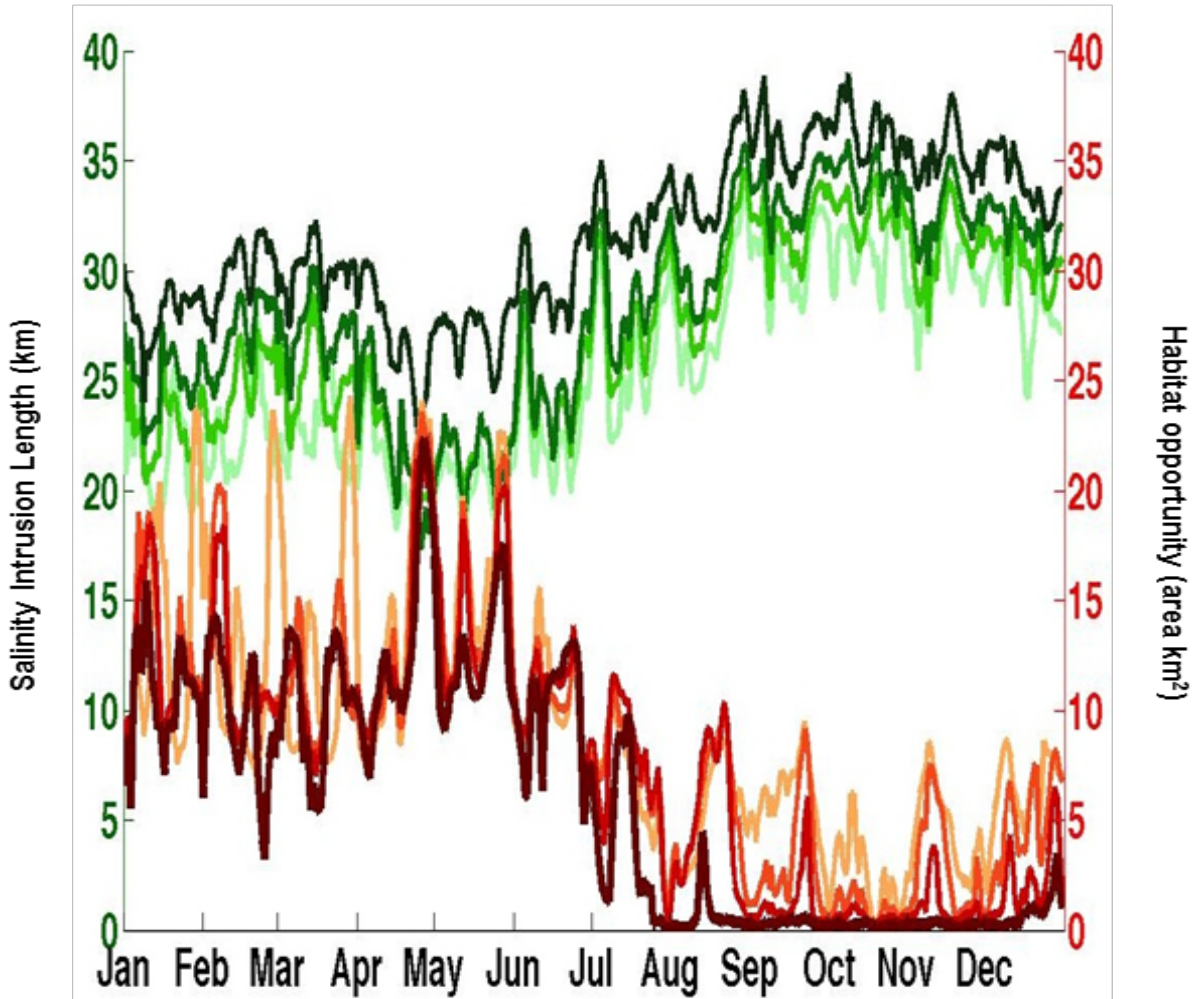


Figure 30. Salinity intrusion (green shades) correlates well visually with habitat opportunity (red shades) in Reach A (as defined here by all individual criteria being met), now and for future scenarios of sea level rise. Lighter tones (in green and red) represent present-day conditions, while increasingly darker tones correspond to increasingly more severe scenarios of sea level change (30, 70 and 130 cm increases).

As for Figures 26-29, we consider the results in Figure 30 illustrative. Once DB29 is complete, and its skill fully assessed, results to date of the impact of sea level rise will be updated.

## SUMMARY AND CONCLUSIONS

In 2010 we initiated an integrated research program to investigate habitat use and performance of juvenile Chinook salmon in selected tidal-fluvial reaches of the Columbia River estuary. The purpose of the research is twofold: determine the estuary's contributions to the spatial structure and diversity of Columbia River salmon stocks, and address critical uncertainties about tidal-fluvial habitat functions that limit estuary restoration and salmon recovery planning. In 2011 we completed our first phase of study, which provided information needed to design finer-resolution surveys of tidal-fluvial habitats. We completed the following research tasks in 2011:

- 1) Bimonthly genetic surveys to determine the distributions of Chinook salmon genetic stock groups throughout the estuary;
- 2) Reconnaissance surveys in hydrogeomorphic reaches E/F to test sampling methods and identify candidate sites for more detailed habitat surveys (beginning in 2012);
- 3) Beach-seine collections of juvenile salmon near the estuary mouth to index stock and life-history diversity of out-migrants and to compare results with simultaneous purse seine collections in deeper channel habitats;
- 4) PIT tag monitoring of tagged salmon to determine stock-specific use of selected off-channel habitats
- 5) Otolith analyses to compare juvenile life-history contributions to adults returning to selected Chinook salmon populations and ESUs;
- 6) Life-cycle modeling to analyze the sensitivities of selected populations/stocks to estuary survival improvements; and
- 7) Hydrological modeling to investigate the sensitivities of selected salmon stocks and life histories to habitat-opportunity changes at multiple spatial scales (i.e., among estuary reaches, and among habitat complexes within a reach).

We draw the following conclusions from the 2011 results:

- Chinook salmon stocks and life histories are not uniformly distributed through the estuary but exhibit broad seasonal and spatial patterns that are generally consistent between years.
- Stock diversity and evenness for juvenile Chinook salmon are highest in upper-estuary reaches F and G, reflecting a diverse mixture of Willamette River, lower basin, and interior stock groups. The diverse but poorly-studied habitats in Reach F (i.e., Lewis River confluence to Willamette R. confluence) should be a high priority for future research in the tidal-fluvial estuary.
- The size-dependent pattern of habitat use by juvenile Chinook salmon in 2011 was similar to results previously documented: greater proportions of small subyearlings (i.e., fry and fingerlings) and smaller proportions of large yearlings occur in shallow, near-shore

habitats (i.e., sampled with the beach seine) than occur in deep channel habitats (i.e., sampled with a purse seine) of the lower estuary.

- The proportions of marked hatchery Chinook salmon in beach-seine catches at the estuary mouth increase with each successive size class (i.e., fry, fingerling, yearling), suggesting a substantial hatchery influence on phenotypic variation in the estuary. Phenotypic selection by hatchery programs is particularly evident in the high proportions of marked individuals among larger subyearling and yearling Chinook salmon.
- Tagged individuals from a diversity of species and stocks, including individuals from the interior basin, utilize emergent, scrub-shrub, and forested wetlands along the estuary tidal gradient. Although small unmarked fry and fingerlings are typically most abundant in shallow wetland channels, large subyearling and yearling salmon, including hatchery-reared individuals, also enter these habitats.
- Reconnaissance surveys in Reach F indicate that a diversity of shallow, forested habitats in reach F can be sampled with conventional gear (beach seine, trap nets) but habitat complexity and large amounts of wood debris limit sampling efficiencies. Quantitative comparisons of fish abundance among habitat types and time periods may not be possible because rapidly changing flow and depth conditions greatly affect gear efficiencies at each site.
- A diversity of Chinook stocks, including various interior stocks access the tidal floodplain near Sauvie Island (Reach F) during high flows. The importance of these habitats to juvenile salmon performance (e.g., growth, foraging success, survival) is not known.
- Otolith analyses indicate that multiple juvenile life histories contribute to adult returns in lower, mid-, and upper Columbia River ESUs.
- Among surviving adults from different ESUs, juvenile size at salt-water entry is not a simple function of the distance travelled from natal spawning and rearing areas. Studies of additional populations and return years are needed to understand life history variations that sustain adult returns in different Columbia River ESUs.
- Experimental studies suggest that stock- and stage-specific relationships between otolith radius and fish length may affect the accuracy of back-calculations for size at estuary/ocean entry. Validation of these relationships may be particularly important when comparing results for stocks with very different growth and rearing histories.
- Stock-specific data collected in the estuary can be used to improve life-cycle models and to establish explicit survival values through the estuary.
- Life-cycle model results for Snake River spring/summer Chinook populations suggest that small increases in estuary survival generate significant improvements in population viability.
- Hydrologic modeling shows a strong influence of seasonal river flow and temperature criteria on habitat-opportunity for juvenile salmon in Reach F. Further investigation is

needed to explain an apparent threshold in modeled habitat opportunity at flows  $>7,000 \text{ m}^3/\text{s}$ .

- Modeling scenarios suggest that salmon habitat opportunities in the estuary could be sensitive to future sea-level rise because of increased salinity intrusion, particularly during summer and fall. In this case, habitat opportunity is defined by the availability of low-salinity habitat ( $<5 \text{ psu}$ ) in reach A where subyearling migrants could gradually acclimate to salt water.
- Preliminary modeling suggests that physical habitat opportunities for particular salmon size classes (i.e., life histories) may be highly sensitive in some estuary reaches. Additional refinements in the opportunity criteria are needed to further explore stock-specific and size-specific changes in habitat opportunity.

## REFERENCES

- Baptista, A. M., Zhang, Y. L., Chawla, A., Zulauf, M., Seaton, C., Myers, E. P., III, Kindle, J., Wilkin, M., Burla, M., & Turner, P. J. 2005. A cross-scale model for 3D baroclinic circulation in estuary-plume-shelf systems: II. Application to the Columbia River. *Continental Shelf Research*, 25: 935-972.
- Baptista, A., Howe, B., Freire, J., Maier, D., & Silva, C. 2008. Scientific Exploration in the Era of Ocean Observatories. *Computing in Science & Engineering*, 10(3): 53-58.
- Bottom, D., G. Anderson, A. Baptista, J. Burke, M. Burla, M. Bhuthimethee, L. Campbell, E. Casillas, S. Hinton, K. Jacobson, D. Jay, R. McNatt, P. Moran, G. Roegner, C. Simenstad, V. Stamatiou, D. Teel and J. Zamon. 2008. Salmon life histories, habitat, and food webs in the Columbia River Estuary: an overview of research results, 2002-2006. Fish Ecology Division, NOAA Fisheries, Northwest Fisheries Science Center, Seattle, WA.
- Bottom, D.L., A. Baptista, J. Burke, L. Campbell, E. Casillas, B. Craig, C. Eaton, S. Hinton, K. Jacobson, D. Jay, M. A. Lott, R. McNatt, G.C. Roegner, S. Schroder, C.A. Simenstad, S. Spilseth, V. Stamatiou, D. Teel, and J.E. Zamon. 2011. Salmon Life Histories, Habitat, and Food Webs in the Columbia River Estuary: Final Report 2002-08. Report of Research by Fish Ecology Division, NOAA Fisheries to Portland District, U.S. Army Corps of Engineers. 200 pgs.
- Bottom, D. L., C. A. Simenstad, A. M. Baptista, D. A. Jay, J. Burke, K. K. Jones, E. Casillas, and M. H. Schiewe. 2005. Salmon at River's End: The role of the estuary in the decline and recovery of Columbia River salmon. NOAA Technical Memorandum NMFS-NWFSC-68. 246pp.
- Bottom, D. L., C. A. Simenstad, L. Campbell, J. Burke, E. Casillas, B. Craig, C. Eaton, S. Hinton, R. McNatt, G. C. Roegner, S. Schroder, L. Stamatiou, and J. E. Zamon. 2009. Historic Habitat Opportunities and Food-Web Linkages of Juvenile Salmon in the Columbia River Estuary. Fish Ecology Division, NOAA Fisheries, Northwest Fisheries Science Center, Seattle, WA.
- Burla, M. 2009. The Columbia River Estuary and Plume: Natural Variability, Anthropogenic Change and Physical Habitat for Salmon. Unpublished Doctoral, Oregon Health & Science University, Beaverton.
- Burla, M., Baptista, A. M., Zhang, Y.-L., Casillas, E., Bottom, D. L., & Simenstad, S. A. 2007. Salmon habitat opportunity in the Columbia River estuary: modeling the physical environment to inform management decisions. Paper presented at the Coastal Zone '07, Portland, OR.
- Burla, M., Baptista, A. M., Zhang, Y., & Frolov, S. 2010. Seasonal and interannual variability of the Columbia River plume: A perspective enabled by multi-year simulation databases. *Journal of Geophysical Research, Oceans*, 115(C00B16): 25 pp.

- Campbell, L. A. 2010. Life histories of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River estuary as inferred from scale and otolith microchemistry. Unpubl. M.S. Thesis, Oregon State University, Corvallis, United States.
- Francis, R.I.C.C. 1990. Back-calculation of fish length: a critical review. *Journal of Fish Biology* 36:883:902.
- Fresh, K. L., E. Casillas, L. Johnson, and D. L. Bottom. 2005. Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead: An Evaluation of Limiting Factors. NOAA Technical Memorandum NMFS-NWFSC-69. 105 pp.
- Frolov, S., Baptista, A. M., Y., Z., & Seaton, C. 2009. Estimation of ecologically significant circulation features of the Columbia River estuary and plume using a reduced-dimension Kalman filter. *Continental Shelf Research*, 29(2): 456-466.
- Good, T. P., R. S. Waples, and P. Adams (eds). 2005. Updated status of federally listed ESUs of West Coast salmon and steelhead. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-66.
- Interior Columbia Technical Recovery Team (ICTRT) and R. W. Zabel. 2007. Assessing the Impact of Environmental Conditions and Hydropower on Population Productivity for Interior Columbia River Stream-type Chinook and Steelhead Populations. Available at: [http://www.nwfsc.noaa.gov/trt/col/trt\\_ic\\_viability\\_survival.cfm](http://www.nwfsc.noaa.gov/trt/col/trt_ic_viability_survival.cfm)
- Kalinowski, S. T., K. R. Manlove, and M. L. Taper. 2007. ONCOR a computer program for genetic stock identification. Montana State University, Department of Ecology, Bozeman. Available: [www.montana.edu/kalinowski/Software/ONCOR.html](http://www.montana.edu/kalinowski/Software/ONCOR.html). (April 2011).
- McMichael, G. A., R. A. Harnish, J. R. Skalski, K. A. Deters, K. D. Ham, R. L. Townsend, P. S. Titzler, Hughes, M. S., J. Kim, and D. M. Trott. 2011. Migratory behavior and survival of juvenile salmonids in the lower Columbia River, estuary, and plume in 2010. PNPL-20443, Pacific Northwest National Laboratory, Richland, Washington.
- Myers, J., C. Busack, D. Rawding, A. Marshall, D. Teel, D. M. Van Doornik, and M. T. Maher. 2006. Historical population structure of Pacific salmonids in the Willamette River and lower Columbia River basins. U. S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-73, 311p.
- Narum, S .R., J. J. Stephenson, and M .R. Campbell. 2007. Genetic Variation and Structure of Chinook Salmon Life History Types in the Snake River. *Transactions of the American Fisheries Society* 136:1253-1262.
- Narum, S.R., J.E. Hess, and A. P. Matala. 2010. Examining Genetic Lineages of Chinook Salmon in the Columbia River Basin. *Transactions of the American Fisheries Society* 139:1465-1477.
- North, J., M. Miller, J. Sewall, T. Jones, A. Dietrichs, and T. Miethe. 2006. Select area fishery evaluation project, 1993-2005 Final Report. Project No. 199306000, 255 electronic pages, (BPA Report DOE/BP-00004121-1).
- Rannala, B., and J. L. Mountain. 1997. Detecting immigration by using multilocus genotypes. *Proceedings of the National Academy of Sciences of the USA* 94:9197-9201.
- Roegner, G.C., A. Baptista, D. L. Bottom, J. Burke, L. Campbell, C. Elliot, S. Hinton, D. Jay, M.A. Lott, T. Lundrigan, R. McNatt, P. Moran, C. A. Simenstad, D. Teel, E. Volk, J. Zamon, and E. Casillas. 2008b. Estuarine habitat and juvenile salmon--current and historical linkages in the lower Columbia River and estuary, 2002-04. Fish Ecology Division, Northwest Fisheries Science Center, Seattle, WA.
- Roegner, G.C., E.W. Dawley, M. Russell, A. Whiting, D.J. Teel. 2010. Juvenile salmonid use of reconnected tidal freshwater wetlands in Grays River, lower Columbia River basin. *Transactions of the American Fisheries Society* 139: 1211-1232.



- Roegner, G.C., H. L. Diefenderfer, A. B. Borde, R. M. Thom, E. M. Dawley, A. H. Whiting, S. A. Zimmerman, and G. E. Johnson. 2009. Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary. NOAA Technical Memorandum NMFS-NWFSC-97.
- Roegner G.C., R. McNatt, D. Teel, D. Bottom. 2012. Distribution, size, and origin of juvenile Chinook salmon in shallow water habitats of the lower Columbia River and estuary, 2002-2007. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 4: 450-472.
- Sather, N. K., E. M. Dawley, G. E. Johnson, S. A. Zimmerman, A. J. Storch, A. B. Borde, D. J. Teel, C. Mallette, J. R. Skalski, R. Farr, T. A. Jones. 2009. Ecology of Juvenile Salmon in Shallow Tidal Freshwater Habitats in the Vicinity of the Sandy River Delta, Lower Columbia River, 2008. PNNL-18450, final report submitted to the Bonneville Power Administration by Pacific Northwest National Laboratory, Oregon Department of Fish and Wildlife, National Marine Fisheries Service, and University of Washington.
- Seeb, L. W., A. Antonovich, M. A. Banks, T. D. Beacham, M. R. Bellinger, S. M. Blankenship, M. R. Campbell, N. A. Decovich, J. C. Garza, C. M. Guthrie III, T. A. Lundrigan, P. Moran, S. R. Narum, J. J. Stephenson, K. T. Supernault, D. J. Teel, W. D. Templin, J. K. Wenburg, S. F. Young, and C. T. Smith. 2007. Development of a standardized DNA database for Chinook salmon. *Fisheries* 32:540–552.
- Simenstad, C. A., Burke, J. L., O'Connor, J. E., Cannon, C., Heatwole, D. W., Ramirez, M. F., Waite, I. R., Counihan, T. D., & Jones, K. L. 2011. Columbia River Estuary Ecosystem Classification—Concept and Application.
- Simenstad, C.A., J.L. Burke, I.R. Waite, T.D. Counihan, and J.R. Hatten. 2005. Columbia River estuarine ecosystem classification. Phase II report prepared for Lower Columbia River Estuary Partnership. School Aquat. Fish. Sci., University of Washington, Seattle, WA; and US Geological Survey, Water Resources Discipline, Oregon District Office, Portland, OR, and Biological Resources Discipline, Western Fisheries Research Center, Columbia River Research Laboratory, Cook, WA.
- Teel, D. J., C. Baker, D. R. Kuligowski, T. A. Friesen, and B. Shields. 2009. Genetic stock composition of subyearling Chinook salmon in seasonal floodplain wetlands of the Lower Willamette River. *Transactions of the American Fisheries Society* 138:211-217.
- Volk, E. C., D. L. Bottom, K. K. Jones, and C. A. Simenstad. 2010. Reconstructing juvenile Chinook salmon life history in the Salmon River estuary, Oregon, using otolith microchemistry and microstructure. *Transactions of the American Fisheries Society*. 139:535-549.
- Waples, R. S., D. J. Teel, J. M. Myers, and A. R. Marshall 2004. Life-history divergence in Chinook salmon: Historic contingency and parallel evolution. *Evolution* 58:386-403.
- Zabel, R. W., K. Haught, and P. M. Chittaro. 2010. Variability in fish size/otolith radius relationships among populations of Chinook salmon. *Environmental Biology of Fishes* 89:267-278.
- Zabel, R. W., M. D. Scheuerell, M. M. McClure, and J. G. Williams. 2006. The interplay between climate variability and density dependence in the population viability of Chinook salmon. *Conservation Biology* 20(1):190-200.
- Zhang, Y., Baptista, A. M., & Myers, E. P. 2004. A cross-scale model for 3D baroclinic circulation in estuary-plume-shelf systems: I. Formulation and skill assessment. *Continental Shelf Research*, 24: 2187-2214.

## Appendices

Appendix Table 1. Chinook salmon populations used as baseline data for genetic stock identification analysis in this study. Genetic stock group, evolutionarily significant unit (ESU), source, run time (Sp = spring, Su = summer, F = fall), and sample size are given. ESUs (Good et al. 2005) are (1) = Snake River spring/ summer, (2) = Snake River fall, (3) = Middle Columbia River spring, (4) = Upper Columbia River spring, (5) = Upper Columbia River summer/fall, (6) = Deschutes River, (7) = Lower Columbia River, (8) = Upper Willamette River, (9) = Southern Oregon and Northern California Coastal, (10) = Washington Coast, and (11) = Oregon Coast. Populations marked with an asterisk are outside the geographic boundary of the given ESU but are included in the stock group based on genetic similarity. Genetic data are from Seeb et al. (2007) except where noted.

Genetic stock group (ESU)	Source populations	Run time	Sample size
Snake River Spring/Summer (1)	Imnaha River	Summer	144
	Minam River	Spring	144
	Rapid River Hatchery	Spring	144
	Secech River	Summer	144
	Tucannon River <sup>3</sup>	Spring	136
	Tucannon Hatchery	Spring	42
	Newsome Creek <sup>4</sup>	Spring	95
	West Fork Yankee Creek <sup>4</sup>	Spring	60
Snake River Fall (2)	Lyons Ferry Hatchery	Fall	186
Mid and Upper Columbia River Spring (3,4)	Carson Hatchery*	Spring	144
	John Day River	Spring	143
	Upper Yakima River	Spring	199
	Warm Springs Hatchery	Spring	143
	Wenatchee River	Spring	62
	Wenatchee Hatchery <sup>3</sup>	Spring	49
	Hanford Reach	Fall	284
Upper Columbia River Summer/Fall (5)	Methow River	Summer	143
	Wells Hatchery	Summer	144
	Wenatchee River <sup>3</sup>	Summer	135
	Lower Deschutes River	Fall	144
Deschutes River Fall (6)	Upper Deschutes River <sup>2</sup>	Fall	144
	Spring Creek Hatchery	Fall	144
Spring Creek Group Tule Fall (7)	Big Creek Hatchery <sup>1</sup>	Fall	99
	Elochoman River <sup>1</sup>	Fall	95
	Willamette River* <sup>1</sup>	Fall	46
	North Fork Clackamas River* <sup>1</sup>	Spring	80
Willamette River Spring (8)	North Santiam Hatchery	Spring	143
	North Santiam River <sup>1</sup>	Spring	96
	Mckenzie Hatchery	Spring	142

	Mckenzie River <sup>1</sup>	Spring	98
West Cascade Tributary Spring (7)	Cowlitz Hatchery	Spring	140
	Kalama Hatchery	Spring	144
	Lewis Hatchery	Spring	144
West Cascade Tributary Fall (7)	Cowlitz Hatchery	Fall	140
	Lewis River	Fall	93
	Sandy River	Fall	124
Rogue River (9)	Cole Rivers Hatchery	Spring	142
	Applegate River	Fall	143
Washington and Oregon coastal (10,11)	Forks Creek Hatchery <sup>3</sup>	Fall	142
	Humptulips Hatchery <sup>3</sup>	Fall	83
	Necanicum River <sup>5</sup>	Fall	77
	Nehalem River <sup>5</sup>	Fall	151
	Kilchis River <sup>5</sup>	Fall	58
	Wilson River <sup>5</sup>	Fall	139
	Trask River <sup>5</sup>	Fall	162

<sup>1</sup> Northwest Fisheries Science Center, D. Teel unpublished data.

<sup>2</sup> Narum et al. (2010)

<sup>3</sup> Washington Department of Fish and Wildlife, S. Blankenship unpublished data.

<sup>4</sup> Narum et al. (2007)

<sup>5</sup> Oregon State University, R. Bellinger unpublished data

Appendix Table 2. Sample sizes, percentages marked, and estimated proportional composition of the 11 genetic stock groups observed in samples of yearling, fingerling, and fry-sized Chinook salmon in the Columbia River estuary, 2010-2012. Range below each estimate shows a 95% confidence interval derived from 100 bootstrap resamplings of baseline and mixed-stock genotypes.

Estuary Reach		Proportional stock composition of Chinook salmon (%)										
		West Cascade tributary		Willamette	Spring	Deschutes	Mid/upper	Upper	Snake River		Rogue	Coast
		Fall	Spring	River spring	Creek group fall	River fall	Columbia River spring	Columbia Summer/fall	Fall	Spring	River fall	fall/spring
<b>All samples, all seasons</b>												
All Reaches	3,631	0.505	0.053	0.077	0.157	0.017	0.001	0.163	0.018	0.001	0.005	0.003
27.8%		0.454-0.509	0.058-0.089	0.061-0.080	0.124-0.168	0.010-0.028	0.000-0.003	0.145-0.182	0.013-0.035	0.000-0.003	0.003-0.009	0.002-0.007
A	264	0.392	0.042	0.019	0.390	0.000	0.000	0.070	0.000	0.000	0.068	0.019
53.0%		0.320-0.482	0.018-0.091	0.003-0.030	0.292-0.428	0.000-0.024	0.000-0.010	0.035-0.101	0.000-0.002	0.000-0.000	0.034-0.091	0.004-0.044
C	515	0.744	0.102	0.045	0.072	0.000	0.000	0.019	0.005	0.002	0.004	0.008
26.4%		0.639-0.754	0.086-0.169	0.024-0.066	0.044-0.100	0.000-0.006	0.000-0.004	0.015-0.055	0.000-0.015	0.000-0.008	0.000-0.011	0.000-0.019
D	761	0.772	0.085	0.044	0.081	0.001	0.000	0.017	0.000	0.000	0.000	0.000
24.3%		0.680-0.785	0.083-0.144	0.027-0.059	0.049-0.110	0.000-0.008	0.000-0.001	0.009-0.040	0.000-0.010	0.000-0.002	0.000-0.003	0.000-0.007
E	720	0.568	0.016	0.111	0.138	0.013	0.000	0.142	0.011	0.000	0.000	0.000
18.1%		0.488-0.578	0.015-0.067	0.081-0.131	0.107-0.164	0.002-0.027	0.000-0.000	0.115-0.180	0.003-0.032	0.000-0.003	0.000-0.006	0.000-0.008
F	569	0.282	0.047	0.177	0.254	0.024	0.004	0.187	0.026	0.000	0.000	0.000
38.1%		0.222-0.343	0.033-0.095	0.130-0.203	0.198-0.281	0.010-0.055	0.000-0.009	0.147-0.241	0.011-0.054	0.000-0.002	0.000-0.004	0.000-0.006
G	441	0.366	0.042	0.092	0.154	0.040	0.005	0.261	0.034	0.002	0.000	0.006
27.7%		0.296-0.395	0.033-0.081	0.054-0.109	0.107-0.180	0.012-0.069	0.000-0.011	0.200-0.319	0.017-0.090	0.000-0.007	0.000-0.008	0.000-0.015
H	361	0.041	0.009	0.004	0.165	0.059	0.000	0.640	0.070	0.011	0.000	0.000
22.4%		0.021-0.089	0.000-0.024	0.000-0.013	0.112-0.192	0.025-0.113	0.000-0.008	0.531-0.681	0.043-0.130	0.000-0.022	0.000-0.005	0.000-0.006
<b>January</b>												
C/D fry <sup>a</sup>	102	0.503	0.387	0.011	0.099	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.0%		0.315-0.589	0.305-0.511	0.000-0.040	0.0290-0.166	0.000-0.000	0.000-0.000	0.000-0.038	0.000-0.026	0.000-0.000	0.000-0.010	0.000-0.000
E/F fry <sup>a</sup>	59	0.365	0.040	0.388	0.190	0.000	0.000	0.000	0.017	0.000	0.000	0.000
0.0%		0.2199-0.523	0.007-0.194	0.271-0.497	0.017-0.246	0.000-0.034	0.000-0.000	0.000-0.051	0.000-0.035	0.000-0.000	0.000-0.000	0.000-0.000
E yearlings <sup>a</sup>	39	0.534	0.000	0.353	0.038	0.028	0.000	0.046	0.000	0.000	0.000	0.000
17.9%		0.305-0.646	0.000-0.129	0.187-0.488	0.000-0.089	0.000-0.108	0.000-0.000	0.000-0.181	0.000-0.025	0.000-0.000	0.000-0.000	0.000-0.026
<b>March</b>												

Proportional stock composition of Chinook salmon (%)												
Estuary Reach		West Cascade tributary		Willamette River	Spring Creek group	Deschutes River	Mid/upper Columbia River	Upper Columbia Summer/fall	Snake River		Rogue River	Coast
Percent marked	N	Fall	Spring	spring	fall	fall	spring	fall	Fall	Spring	fall	fall/spring
A fry	37	0.499	0.114	0.000	0.388	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.0%		0.281-0.739	0.000-0.258	0.000-0.000	0.122-0.522	0.000-0.000	0.000-0.000	0.000-0.032	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000
C fry	81	0.806	0.046	0.000	0.148	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.0%		0.609-0.860	0.012-0.217	0.000-0.008	0.044-0.244	0.000-0.013	0.000-0.000	0.000-0.059	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.035
C yearlings	46	0.048	0.455	0.470	0.000	0.000	0.000	0.005	0.000	0.022	0.000	0.000
91.3%		0.000-0.132	0.274-0.564	0.300-0.617	0.000-0.039	0.000-0.021	0.000-0.063	0.000-0.082	0.000-0.038	0.000-0.086	0.000-0.000	0.000-0.020
D fry <sup>b</sup>	198	0.832	0.029	0.005	0.116	0.000	0.000	0.014	0.004	0.000	0.000	0.000
0.0%		0.702-0.873	0.020-0.118	0.000-0.016	0.040-0.166	0.000-0.014	0.000-0.000	0.000-0.042	0.000-0.025	0.000-0.000	0.000-0.000	0.000-0.021
D yearlings <sup>b</sup>	54	0.080	0.361	0.551	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000
87.0%		0.019-0.202	0.237-0.509	0.369-0.675	0.000-0.039	0.000-0.011	0.000-0.037	0.000-0.017	0.000-0.000	0.000-0.000	0.000-0.044	0.000-0.000
E fry <sup>b</sup>	108	0.638	0.004	0.029	0.313	0.017	0.000	0.000	0.000	0.000	0.000	0.000
0.9%		0.554-0.765	0.000-0.070	0.009-0.073	0.139-0.341	0.000-0.037	0.000-0.000	0.000-0.039	0.000-0.022	0.000-0.000	0.000-0.028	0.000-0.019
E yearlings <sup>b</sup>	44	0.045	0.091	0.840	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.000
38.6%		0.000-0.097	0.000-0.187	0.712-0.934	0.000-0.068	0.000-0.047	0.000-0.000	0.000-0.089	0.000-0.040	0.000-0.000	0.000-0.000	0.000-0.000
F fry <sup>b</sup>	91	0.159	0.082	0.349	0.385	0.000	0.000	0.000	0.025	0.000	0.000	0.000
0.0%		0.084-0.277	0.021-0.177	0.227-0.447	0.231-0.467	0.000-0.029	0.000-0.000	0.000-0.051	0.000-0.044	0.000-0.000	0.000-0.022	0.000-0.000
F yearlings <sup>b</sup>	48	0.000	0.112	0.888	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
75.0%		0.000-0.014	0.024-0.259	0.709-0.961	0.000-0.000	0.000-0.000	0.000-0.001	0.000-0.048	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000
G/H fry <sup>c</sup>	66	0.092	0.017	0.000	0.495	0.098	0.000	0.249	0.048	0.000	0.000	0.000
1.5%		0.021-0.191	0.000-0.064	0.000-0.060	0.321-0.565	0.013-0.205	0.000-0.000	0.125-0.386	0.000-0.136	0.000-0.000	0.000-0.000	0.000-0.000
<b>May</b>												
A fingerlings	77	0.035	0.013	0.000	0.953	0.000	0.000	0.000	0.000	0.000	0.000	0.000
96.1%		0.011-0.148	0.000-0.068	0.000-0.000	0.784-0.974	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000
C fry	135	0.932	0.009	0.016	0.010	0.000	0.000	0.000	0.000	0.002	0.011	0.020
0.0%		0.768-0.945	0.006-0.127	0.000-0.023	0.000-0.071	0.000-0.014	0.000-0.013	0.000-0.049	0.000-0.023	0.000-0.010	0.000-0.025	0.000-0.042
C fingerlings	33	0.521	0.056	0.000	0.422	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33.3%		0.311-0.697	0.000-0.209	0.000-0.036	0.224-0.552	0.000-0.030	0.000-0.000	0.000-0.070	0.000-0.055	0.000-0.000	0.000-0.000	0.000-0.057
D fry	138	0.951	0.023	0.007	0.000	0.000	0.000	0.019	0.000	0.000	0.000	0.000
0.0%		0.810-0.949	0.008-0.110	0.000-0.022	0.000-0.051	0.000-0.024	0.000-0.000	0.000-0.085	0.000-0.002	0.000-0.007	0.000-0.000	0.000-0.010
D fingerlings	42	0.459	0.043	0.000	0.498	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50.0%		0.271-0.583	0.000-0.165	0.000-0.047	0.325-0.636	0.000-0.000	0.000-0.000	0.000-0.071	0.000-0.044	0.000-0.000	0.000-0.000	0.000-0.017
E fry	116	0.723	0.000	0.000	0.069	0.000	0.000	0.173	0.035	0.000	0.000	0.000
2.6%		0.561-0.785	0.000-0.069	0.000-0.000	0.016-0.134	0.000-0.025	0.000-0.000	0.107-0.264	0.000-0.084	0.000-0.000	0.000-0.016	0.000-0.007



Proportional stock composition of Chinook salmon (%)												
Estuary Reach		West Cascade tributary		Willamette River	Spring Creek group	Deschutes River	Mid/upper Columbia River	Upper Columbia Summer/fall	Snake River		Rogue River	Coast
Percent marked	N	Fall	Spring	spring	fall	fall	spring	fall	Fall	Spring	fall	fall/spring
E fingerlings	64	0.159	0.000	0.044	0.781	0.000	0.000	0.017	0.000	0.000	0.000	0.000
82.8%		0.072-0.303	0.000-0.057	0.000-0.093	0.612-0.862	0.000-0.040	0.000-0.000	0.000-0.064	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.026
F fry	82	0.495	0.040	0.037	0.199	0.027	0.000	0.192	0.010	0.000	0.000	0.000
4.9%		0.315-0.578	0.000-0.137	0.000-0.084	0.109-0.321	0.000-0.086	0.000-0.000	0.103-0.297	0.000-0.059	0.000-0.005	0.000-0.000	0.000-0.033
F fingerlings	94	0.106	0.028	0.022	0.845	0.000	0.000	0.000	0.000	0.000	0.000	0.000
89.4%		0.051-0.229	0.000-0.118	0.000-0.043	0.665-0.896	0.000-0.000	0.000-0.000	0.000-0.025	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.000
G fry	131	0.511	0.000	0.026	0.055	0.043	0.000	0.335	0.023	0.000	0.000	0.007
3.8%		0.387-0.567	0.000-0.068	0.000-0.057	0.011-0.093	0.000-0.117	0.000-0.000	0.242-0.448	0.000-0.103	0.000-0.000	0.000-0.020	0.000-0.030
G fingerlings	50	0.221	0.057	0.020	0.702	0.000	0.000	0.000	0.000	0.000	0.000	0.000
92.0%		0.065-0.374	0.000-0.150	0.000-0.081	0.469-0.803	0.000-0.000	0.000-0.000	0.000-0.026	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.060
H Fry	111	0.065	0.000	0.000	0.036	0.045	0.000	0.752	0.103	0.000	0.000	0.000
0.0%		0.009-0.138	0.000-0.011	0.000-0.000	0.000-0.072	0.000-0.136	0.000-0.000	0.572-0.829	0.023-0.237	0.000-0.018	0.000-0.018	0.000-0.014
H fingerlings	37	0.028	0.000	0.000	0.781	0.000	0.027	0.078	0.086	0.000	0.000	0.000
70.3%		0.000-0.208	0.000-0.056	0.000-0.000	0.514-0.867	0.000-0.083	0.000-0.054	0.021-0.227	0.000-0.193	0.000-0.054	0.000-0.000	0.000-0.000
<b>July</b>												
A fingerlings <sup>d</sup>	80	0.638	0.000	0.000	0.145	0.002	0.000	0.111	0.000	0.000	0.090	0.013
52.5%		0.499-0.732	0.000-0.078	0.000-0.000	0.046-0.213	0.000-0.054	0.000-0.000	0.027-0.187	0.000-0.020	0.000-0.000	0.025-0.146	0.000-0.061
C fry	25	0.796	0.038	0.000	0.126	0.000	0.000	0.000	0.041	0.000	0.000	0.000
8.0%		0.504-0.892	0.000-0.214	0.000-0.000	0.000-0.276	0.000-0.000	0.000-0.000	0.000-0.173	0.000-0.121	0.000-0.000	0.000-0.080	0.000-0.000
C fingerlings	103	0.795	0.050	0.000	0.026	0.000	0.000	0.108	0.001	0.000	0.010	0.010
45.6%		0.622-0.831	0.017-0.164	0.000-0.004	0.000-0.071	0.000-0.017	0.000-0.000	0.046-0.180	0.000-0.046	0.000-0.000	0.000-0.039	0.000-0.035
D fry	58	0.892	0.054	0.000	0.000	0.000	0.000	0.032	0.022	0.000	0.000	0.000
7.0%		0.693-0.919	0.000-0.152	0.000-0.035	0.000-0.111	0.000-0.071	0.000-0.000	0.000-0.114	0.000-0.066	0.000-0.000	0.000-0.000	0.000-0.033
D fingerlings	122	0.879	0.009	0.000	0.075	0.020	0.000	0.016	0.000	0.000	0.001	0.000
67.2%		0.712-0.893	0.000-0.107	0.000-0.000	0.019-0.162	0.000-0.042	0.000-0.003	0.000-0.059	0.000-0.017	0.000-0.000	0.000-0.023	0.000-0.036
E fry	54	0.860	0.040	0.000	0.000	0.018	0.000	0.082	0.000	0.000	0.000	0.000
1.9%		0.690-0.912	0.000-0.130	0.000-0.037	0.000-0.041	0.000-0.075	0.000-0.000	0.000-0.164	0.000-0.057	0.000-0.000	0.000-0.000	0.000-0.049
E fingerlings	122	0.420	0.016	0.001	0.036	0.052	0.000	0.463	0.012	0.000	0.000	0.000
28.7%		0.265-0.497	0.000-0.071	0.000-0.023	0.000-0.086	0.007-0.118	0.000-0.000	0.324-0.588	0.000-0.110	0.000-0.000	0.000-0.018	0.000-0.034
F Fingerlings	175	0.402	0.031	0.000	0.034	0.050	0.000	0.425	0.056	0.000	0.000	0.000
41.1%		0.293-0.469	0.006-0.072	0.000-0.005	0.001-0.071	0.011-0.110	0.000-0.000	0.309-0.530	0.008-0.142	0.000-0.000	0.000-0.010	0.000-0.021
G fingerlings	142	0.453	0.016	0.014	0.052	0.053	0.000	0.367	0.039	0.000	0.000	0.007
45.8%		0.343-0.502	0.000-0.065	0.000-0.035	0.007-0.106	0.000-0.098	0.000-0.000	0.247-0.445	0.005-0.164	0.000-0.000	0.000-0.014	0.000-0.021

Proportional stock composition of Chinook salmon (%)												
Estuary Reach		West Cascade tributary		Willamette River	Spring Creek group	Deschutes River	Mid/upper Columbia River	Upper Columbia Summer/fall	Snake River		Rogue River	Coast
Percent marked	N	Fall	Spring	spring	fall	fall	spring	fall	Fall	Spring	fall	fall/spring
H fingerlings	134	0.037	0.000	0.008	0.000	0.094	0.000	0.795	0.058	0.008	0.000	0.000
36.6%		0.002-0.096	0.000-0.021	0.000-0.028	0.000-0.020	0.015-0.149	0.000-0.000	0.617-0.834	0.017-0.178	0.000-0.022	0.000-0.009	0.000-0.000

#### September/November

A fingerlings	39	0.406	0.055	0.000	0.000	0.000	0.000	0.197	0.000	0.000	0.239	0.104
30.8%		0.196-0.564	0.000-0.144	0.000-0.000	0.000-0.076	0.000-0.102	0.000-0.000	0.044-0.319	0.000-0.094	0.000-0.000	0.103-0.382	0.024-0.237
C fingerlings	76	0.887	0.042	0.013	0.043	0.000	0.000	0.004	0.000	0.000	0.000	0.012
44.7%		0.700-0.916	0.013-0.177	0.000-0.043	0.000-0.136	0.000-0.000	0.000-0.000	0.000-0.055	0.000-0.027	0.000-0.000	0.000-0.007	0.000-0.056
D fingerlings	56	0.940	0.025	0.017	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000
50.0%		0.730-0.986	0.000-0.153	0.000-0.042	0.000-0.099	0.000-0.036	0.000-0.000	0.000-0.072	0.000-0.000	0.000-0.000	0.000-0.000	0.000-0.017
E fingerlings	107	0.768	0.030	0.041	0.010	0.000	0.000	0.135	0.007	0.000	0.008	0.000
46.7%		0.569-0.790	0.000-0.127	0.000-0.081	0.000-0.060	0.000-0.029	0.000-0.012	0.055-0.231	0.000-0.055	0.000-0.019	0.000-0.038	0.000-0.037
F fingerlings	51	0.363	0.108	0.179	0.018	0.069	0.000	0.233	0.030	0.000	0.000	0.000
23.5%		0.187-0.460	0.026-0.261	0.076-0.324	0.000-0.057	0.000-0.167	0.000-0.000	0.098-0.381	0.000-0.159	0.000-0.000	0.000-0.039	0.000-0.017
G fingerlings	63	0.149	0.147	0.492	0.000	0.000	0.000	0.172	0.010	0.016	0.000	0.015
4.8%		0.038-0.237	0.039-0.237	0.313-0.625	0.000-0.045	0.000-0.083	0.000-0.032	0.032-0.295	0.000-0.138	0.000-0.048	0.000-0.000	0.000-0.055
H fingerlings	32	0.000	0.101	0.037	0.055	0.000	0.000	0.722	0.044	0.042	0.000	0.000
15.6%		0.000-0.124	0.000-0.221	0.000-0.049	0.000-0.094	0.000-0.158	0.000-0.051	0.476-0.875	0.000-0.220	0.000-0.125	0.000-0.061	0.000-0.062

<sup>a</sup> Includes samples collected in February 8 and 9 2011

<sup>b</sup> Includes samples collected April 12, 26 and 27 2011

<sup>c</sup> Includes samples collected April 3 and 7 2012

<sup>d</sup> Includes samples collected June 30 2011

### Appendix 3. PAB fish community

Of the entire fish community in 2010 and 2011, threespine stickleback dominated the catch (54.6%), followed by Chinook salmon (10.7%), surf smelt (6.6%), English sole (3.4%) and shiner perch (3.0%), with all other species < 1.0%. However, these combined annual percentages of the dominant species belie wide annual fluctuations in catches, both between 2010 and 2012 as well as from previous years (Appendix Table A3; Figures A1 & A2). We ranked the abundance of the 15 most abundant species ( $\geq 0.1\%$ ) excluding stickleback, and compared those ranks to the data collected from 2002-2007. Shiner perch were the most abundant species after stickleback in previous years, but ranked third during both 2010 and 2011. Chinook salmon ranked first in 2011 and English sole ranked first in 2010. Northern anchovy are often abundant but were at low abundance in 2010 and 2011. In addition to abundances, several species exhibit variation in size-at-age, which reflects either reproductive events (e.g. shiner perch) or the presence of juveniles or adults (e.g. English sole, starry flounder).

Table A3. Comparison of species composition ( $\geq 0.1\%$ ) and rank order of fish sampled at Pt. Adams Beach 2010-2011 compared with data from 2002-2007. Threespine stickleback were excluded.

Species	2010	2011	Total 2010- 2011	% 2010	% 2011	% 2010- 2011	Total 2002- 2007	% 2002 2007	Rank 2010	Rank 2011	Rank 2002- 2007
<b>Shiner perch</b>	336	330	666	17.9	9.6	12.5	11646	42.7	3	3	1
<b>Surf smelt</b>	364	1111	1475	19.4	32.4	27.8	7539	27.6	2	2	2
<b>Chinook salmon</b>	282	2067	2349	15.0	60.2	44.2	2371	8.7	4	1	3
<b>English sole</b>	916	7	923	48.8	0.2	17.4	1925	7.1	1	9	4
<b>Northern anchovy</b>	2	0	2	0.1	0.0	0.0	1205	4.4	11	12	5
<b>Staghorn sculpin</b>	122	73	195	6.5	2.1	3.7	766	2.8	5	4	6
<b>Starry flounder</b>	30	26	56	1.6	0.8	1.1	660	2.4	7	8	7
<b>Chum salmon</b>	113	44	157	6.0	1.3	3.0	614	2.2	6	7	8
<b>American shad</b>	5	52	57	0.3	1.5	1.1	202	0.7	10	5	9
<b>Pacific herring</b>	2	1	3	0.1	0.0	0.1	140	0.5	12	11	10
<b>Coho salmon</b>	27	49	76	1.4	1.4	1.4	59	0.2	8	6	11
<b>Pacific sanddab</b>	0	0	0	0.0	0.0	0.0	36	0.1	14	14	12
<b>Sand sole</b>	12	2	14	0.6	0.1	0.3	24	0.1	9	10	13
<b>Saddleback gunnel</b>	2	0	2	0.1	0.0	0.0	22	0.1	13	13	14
<b>Cutthroat trout</b>	0	0	0	0.0	0.0	0.0	15	0.1	15	15	15
<b>Total</b>	1877	3432	5309				15578				

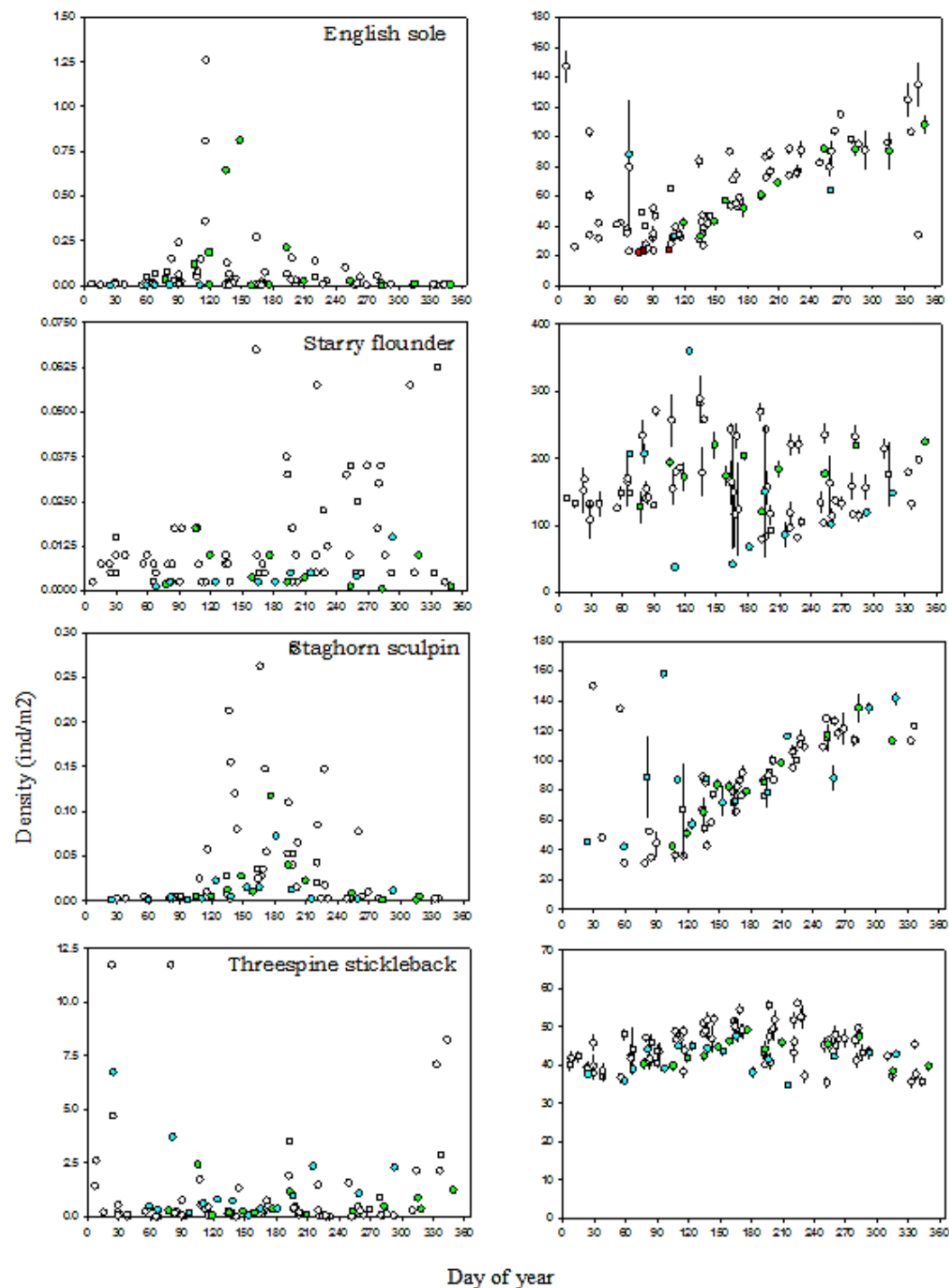


Figure A1. Time series of density (left) and mean fork length (right) for various fishes sampled at PAB during 2010 (green) and 2011 (blue) relative to 2002-2008 (white).

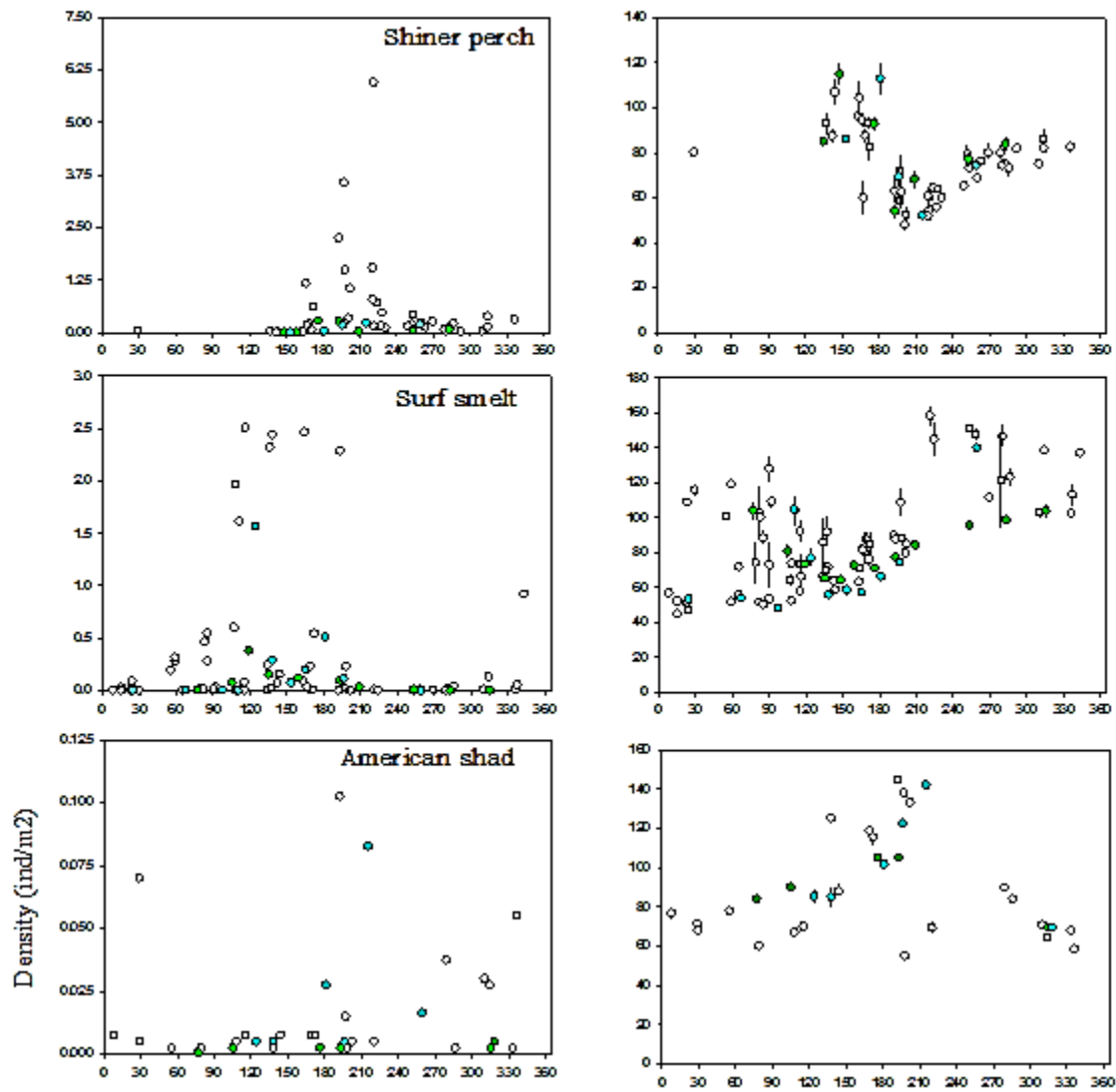


Figure A2. Time series of density (left) and mean fork length (right) for various fishes sampled at PAB during 2010 (green) and 2011 (blue) relative to 2002-2008 (white).